CONSERVATION OF SEVERELY DAMAGED PAPER USING PASSIVATION POLYMERS

A Dissertation

by

ELOISE BRACKENRIDGE EILERT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2011

Major Subject: Anthropology

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Approved by:

Chair of Committee,	Charles W. Smith
Committee Members,	Donny L. Hamilton
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ABSTRACT

Conservation of Severely Damaged Paper

Using Passivation Polymers. (August 2011)

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This work examined the use of passivation polymers in the conservation of severely damaged paper. It specifically investigated the use of this functional polymer treatment to address the issues of damage to paper caused by waterlogging, mold, and internal acidity. Several experiments were designed and conducted to examine the effects of the polymers in the conservation of papers compromised by these conditions. Paper artifacts from the Bonfire Memorabilia Collection were selected and conserved using treatment protocols that included the use of the passivation polymers. The conservation of some of the damaged papers from this culturally important site demonstrated the effectiveness of the polymer treatment in real-world conservation situations. This dissertation established that the use of passivation polymers adds strength and stability to severely damaged paper.

DEDICATION

To my family,

for their love, support, and patience

Thank you so much for everything.

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Most importantly, I would like to thank my family for supporting me through this incredibly lengthy process. My father, Dr. Jeffries Eilert, never stopped believing in me, and never considered any of my many chemistry questions too simple to bother to answer. My mother, Dr. Eugenia Brackenridge, was my sounding board for many ideas and my constant therapist when things got too weird for my brain. She also helped a great deal with the editing of the first versions of this work, without whose help this would have been a garbled mess. I owe both of my parents a great debt for all of the childcare I required to write, research, and travel to complete this dissertation. I also would like to thank them for being great role models for me in pursuing my academic dreams.

My partner in life, Dr. Elmer Linboom, has always supported my pursuits. Following me to strange places and often being left behind, he has loved and accepted my ideas without questioning my choices. Our children have never questioned our choices or wondered why one or the other of us was gone for an extended period of time pursuin g our academic goals, and for that I am thankful for their tolerance. Praise Jah!

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CHAPTER I

INTRODUCTION

This dissertation examines the use of passivation polymers, a solution of functional, silicone-based polymers, for the conservation of severely damaged paper. It specifically investigates the use of this treatment to address issues of paper damaged by waterlogging, mold, and internal acidity. Paper artifacts develop these problems as a result of disasters, excavation, the environment in which the paper is stored, or from the materials used in the production of the paper.

There are many causes of disasters that can affect paper. These include flood, fire, and the resulting water damage to papers from extinguishing the fire all of which can be caused by weather or man-made devastation. Collections damaged from these catastrophes can be removed to safe spaces, like a freezer, but this is not a permanent solution. In order for these papers to be examined again, they will need conservation treatment.

Not surprisingly, paper is a rare find in the archaeological record. It seldom is preserved in the usual archaeological setting of soil excavation. Its chances of surviving increase significantly if it is stored or abandoned in a dry setting, such as a dry cave, or in a submerged setting, such as a shipwreck. Yet, the simple act of exposing these damaged papers to the ambient air can cause them to be irrecoverably damaged.

This dissertation follows the style of *Historical Archaeology.*

Both new and old papers housed in storage facilities are at risk as well. Libraries and museums, considered to be safe repositories, are prone to issues that can cause paper's destruction. If the environment is not carefully monitored within these facilities, incorrect temperature and humidity levels encourage accelerated aging and mold growth in paper.

Paper is not only easily damaged from external influences; the paper itself is an active agent in its own destruction. Modern paper made predominantly from wood pulp often contains high levels of lignin and other acidic compounds, which destroy the paper from the inside matrix. Additionally, some inks and other materials used on paper are unstable and cause additional damage. When paper becomes severely damaged from any of the above mentioned situations, action must be taken to stabilize and conserve it.

This dissertation considers paper from an archaeological conservation perspective. Current methods of paper conservation are explored and the need for new methods is discussed. Experiments using innovative conservation techniques and treatments were conducted to demonstrate new methods of paper conservation. Accordingly, these experiments produced protocols of treatment developed to address significantly compromised and damaged paper. These treatments specifically address paper damaged from waterlogging, mold, internal acidity, and other external environmental forces. Damaged items from the Bonfire Memorabilia Collection at Texas A&M University serve as a case study using these techniques. This work demonstrates and advocates new treatments for the conservation of severely damaged paper.

Present Status of the Question

The methods currently in use by paper conservators are inadequate to preserve severely damaged paper. Severely damaged paper requires a different course of conservation from the established protocols, as a different set of needs must be met to combat the three biggest causes of severe damage to paper. As a result, new conservation methods need to be developed in order to stabilize, conserve, and protect severely damaged paper. Most paper conservators are fine arts or library science paper conservators, and generally do not encounter severely damaged paper. These conventional conservators usually work with art or text on paper that is in relatively good condition, so traditional methods of conservation effectively work. Often, these sorts of items only need minor repairs and a stable environment. But when confronted with compromised and severely damaged paper, the methods they use are not adequate. Such paper has different conservation needs, and has to be stabilized and conserved quickly, or it will disintegrate and be lost forever.

Conventional paper conservation and its practitioners do not always recognize nor acknowledge the necessity of conserving a severely damaged paper artifact that lacks original art or writing. Saving paper for paper's sake is viewed as a waste of resources. Yet, paper found in archaeological contexts has material culture meaning and purpose beyond the images or words written on its surface. Even without writing or designs, archaeological paper holds information for the researcher, such as the materials used in its production, its age, the reasons for its use, and other data.

A discussion of the traditional methods of paper conservation appears later in the work, but none of the current conservation strategies do anything to increase strength or deacidify paper without using very invasive, and sometimes damaging, techniques. Waterlogged paper is a particularly delicate problem, and it is most often placed wet into a freezer, which imparts further damage through the freeze-drying process. Conserving moldy paper is particularly difficult, as the mold can be dangerous to the conservator, and the chemical methods of abatement are most certainly toxic to the conservator. The best method to address mold is through irradiation, which effectively kills the mold colonies, but this leaves the paper in a weakened state. There are several methods of deacidification, but none return any of the strength lost during the degradation of paper. The traditional conservation treatments for all of these issues leave the artifacts in a slightly more stable yet much weaker state.

This dissertation provides a new protocol to conserve severely damaged paper using passivation polymers. Passivation polymers are a mixture of silicone-based functional polymers that add strength to organic artifacts. This work will demonstrate that passivation polymers should be used to conserve severely damaged paper.

Organization

This dissertation is divided into eight chapters. Following this introduction, Chapter II, The History of Paper, discusses paper production, beginning with the evolution and history of paper making, from hand-made to industrially mechanized. It provides a basic overview of the techniques used in both handmade paper and industrial production. The rest of the chapter discusses the material culture of paper, providing a basis for the conservation and preservation of severely damaged paper.

Chapter III, The Chemistry of Paper, describes the composition of paper and its chemistry. It provides a basic understanding of the complex chemical reaction that results in paper. Through an understanding of the general chemistry of paper, it is possible to understand how paper degrades, and how these reactions can be treated.

Chapter IV, Paper Conservation Treatments, addresses the forces that lead to the deterioration of paper, and the current techniques of paper conservation used to address these forces. Conventional library science and fine arts paper conservators are trained extensively in repairing the problems associated with collections management. Yet, when confronted by paper that has been severely damaged from water, mold, or internal acidity, their methods do not provide effective solutions.

Chapter V, Passivation Polymers, concentrates on the science of passivation polymers. A discussion of the chemistry and the mechanics of the polymers is followed by a description of the methods of application and its uses. Other examples of the use of passivation polymers are introduced as well. They add strength and flexibility to other types of organic artifacts that have been severely damaged, so using them to conserve paper is a logical practice.

Chapter VI, Experiments Using Passivation Polymers, focuses on the experiments conducted to evaluate the use of passivation polymers on paper. The papers used in the experiments will be examined to determine an increase in strength and reviewed for texture, color change, thickness and other characteristics. Environmental

Electron Scanning Microscopy (ESEM) shows that passivation polymers reinforce fibers within the matrix of the paper. An independent paper-testing laboratory provides additional data about the use of the polymer treatment on paper. The experiments discussed in this chapter of the dissertation can be found in the appendix.

Chapter VII, Conservation of Paper Artifacts from the Bonfire Memorabilia Collection, reviews the practical application of passivation polymers through case-studies of severely damaged paper artifacts, demonstrating the effectiveness of the conservation methods proposed for severely damaged paper. Case studies are necessary, as they provide real-world conditions and variables that need to be addressed. While it is possible under laboratory conditions to reproduce some of the conditions that led to the damage of the artifacts, only the conservation of damaged artifacts can demonstrate the effectiveness of a conservation treatment. On November 18, 1999, the Bonfire, a Texas A&M University tradition since 1909, collapsed killing twelve students and injuring at least 27 others. Because of the outpouring of grief and remembrance, spontaneous shrines at the site of the collapse and other places were quickly erected. The significance of these shrines and others is discussed in this work as well. The items left by the visitors to the shrines became weather-beaten and deteriorated as a result of environment and weather conditions, and were collected into a group of artifacts known as the Bonfire Memorabilia Collection. Among those contributions left behind, there was a large amount of paper. This disaster paper was affected by many different forces (water, UV light, wind and instability, unstable media, insects, pollen, fungus and poor quality material components) at work degrading the paper.

By examining and conserving these paper artifacts from the Bonfire Memorabilia Collection, a twofold goal is accomplished: 1) the preservation of a sample of this particularly important collection of artifacts and 2) the scientific examination of a comprehensive collection of severely damaged paper artifacts that suffered from exposure to the elements and other forces. The collection is principally important as a conservation study because it represents a group of artifacts that suffered degradation from a group of similar variables. Over 100 artifacts were conserved, including a 1-1.5ft. bundle of mashed up paper, which was discovered to be a 15ft. by 3.5 ft. readable poster after conservation. Each piece of paper or artifact was individually addressed and recorded with photo documentation and a treatment report in the appendix. Additionally, the impact of spontaneous shrines, such as the one that these papers were a part of is discussed, demonstrating the necessity of conserving and preserving this unique collection of artifacts.

Chapter VIII, Conclusion, is the summary of this work, with a discussion of the results and the future of passivation polymers in paper conservation. The fundamental goal of this dissertation is to improve the way severely damaged and degraded paper is conserved and curated. This section reinforces the need for passivation polymers to be used in the conservation of severely damaged paper.

This dissertation provides evidence that passivation polymers should be used in the conservation of severely damaged paper. By examining the history, chemistry, and the problems of paper and its conservation, it becomes clear that new methods need to be developed for paper conservation. Through experimentation and demonstrating through real-world application the use of passivation polymers, a new technique in paper conservation is established for the treatment of severely damaged paper.

CHAPTER II

HISTORY OF PAPER

This chapter begins with an account of the development of paper, from its origins to its spread across nations over time. The later mechanization and industrialization of paper production is also presented. The rest of the chapter discusses the material culture of paper and its significance as an artifact.

The actual invention of paper is not well established. Like many kinds of early manufactured products, it is hard to pinpoint the exact location or date of their invention. Within recent history, a few paper historians and organizations have conducted some relevant research, and the archaeological finds of early paper have made it possible to draw some conclusions about the nature of early paper invention and production.

Paper is different from other plant-based writing materials, such as papyrus. Papyrus as a writing material from the papyrus plant was discovered much earlier than paper, and is considered a proto-paper. It is composed of thin sections of the stalk of the papyrus plant placed horizontally and vertically and then pounded together. The natural resin within the plant acts as an adhesive. It is dried and cut into sheets. The fibers within each layer do not move or interact. Other proto-papers are similar to this manufacture, including tapa and other bark cloths.

To be classified as paper, the product must be made from fibers that are macerated until each fiber is a separate unit. Next, the fibers are suspended in an aqueous solution. Then, a screen or similar sieve-like device is used to lift a thin layer of fibers. Finally, when the layer of fibers is dried, creating a layer of intertwined fibers that compose a sheet, it can be considered to be paper (Hunter 1947).

The historical time frame of paper production is divided into two eras. The first era begins with the earliest paper invention and production up to 1867. The second era began when the Age of Paper began in America (Library of Congress 1968). It is referred to as the Age of Paper because of the three major technological developments that allowed the production of paper to become an industrial enterprise. These developments were the use of wood pulp to replace rags and other materials used for pulp, the further perfection of the mechanical paper making machine, and the use of chemical methods of pulping and bleaching.

Invention in China and the Far East

The history and invention of paper began in China. Many authors credit the invention of paper to a Chinese eunuch named Ts'ai Lun or Cai Lun in 105 CE (Hunter, 1947, 1974; Schlosser 1979; Schreyer 1988; Bloom 2001; BAPH 2006). This is the Just So story of the invention of paper, but it may not be the historically correct date of invention. The 5th century story comes to us from Fan Yeh, writer of the History of the Later or Eastern Han Dynasty (A.D. 25-220) in a chapter devoted to special eunuchs. The paper was recorded as being made of discarded fishing nets, waste hemp, old cloth, and tree bark (paper mulberry) (Needham 1985). It was given the Chinese word zhi, which means mat of refuse fibers (Bloom 2001). Lun presented a sample of this paper to the Emperor Ho Ti in A.D.105. The fate of Ts'ai/Cai Lun was rather unfortunate, as later in his career he became embroiled in palace intrigue. After his participation was discovered, he went home and ritually committed suicide by poison (Hunter 1947; Rudin 1990).

Dard Hunter, perhaps the most famous scholar of paper history, states that the earliest paper found archaeologically can be dated around A.D. 150, made from a rag base (Hunter 1947). Hunter is the most often-quoted of paper historians, and probably provides some of the most relevant information. He is so renowned that there is a museum dedicated to him and preserving early paper production techniques at the Institute of Paper Science and Technology, at the Georgia Institute of Technology. There is also a Dard Hunter annual conference, and even an online “Friends of Dard Hunter” discussion group (http://www.friendsofdardhunter.org 2010). Many, if not all, paper historians reference him and his work (Hopkinson 1978; Schlosser 1979; Needham 1985; Rudin 1990; Bloom 2001). He wrote five different volumes on paper making and production. Papermaking through Eighteen Centuries (1974) and Papermaking, the History and Technique of an Ancient Craft (1947) provide the most relevant historical data. Archeological finds since Hunter’s passing in 1966 have expanded the evidence of early papermaking; nevertheless, his works present excellent historical references.

Recently, a site in Sian (Xian), China dated to the Western Han Dynasty (206 B.C.- A.D. 24) has unearthed over 200 book fragments, and is thought to date to 140-87 B.C. (Heng 2002). Other finds include the 1957 find of 88 sheets of paper made of hemp found in the Baqiao site, in Sian, which are thought to be from the 2nd century

B.C. (Bloom 2001) and the 1986 find of paper in a tomb at the Fangmatan site in Tianshui, Gansu Provence, thought to also be from the Western Han Dynasty (Heng 2002).

Another more recent find of a 10 square centimeter piece of paper, made from linen fibers, was found during the excavation and restoration of an ancient garrison near the Yumen Pass at Dunhuang in northwest China. The garrison was in use during the Western Han Dynasty. Fu Licheng, the curator of the Dunhuang Museum, said, “This is definitely paper and the skill to make it seems quite mature” (Yan 2006). Twenty written characters have been identified, and it thought to be an excerpt from a letter. However, that should not diminish the introduction of paper by Lun. Fu stated that, “Cai Lun’s contribution was to improve this skill systematically and scientifically, fixing a recipe for papermaking,” (Yan 2006). It is not known if the original reason for the invention of paper was for writing, rather than another possible use. But as paper became used for writing, it would have become more refined in its production, providing a better surface for writing (Needham 1985).

According to legend, in 610, papermaking was introduced to Japan by a Buddhist monk named Dokyo or Tamjing (Hunter 1947; Rudin 1990). It is possible one of the reasons that paper made such an impact in Japan was the early attention the Japanese Imperial family, notably the Empress Shotoku, paid to this papermaker. He became the Empress’s personal physician and most trusted advisor. The Empress ordered one million prayers to be dedicated to the temples, some of which survive and provide the first examples of printing. By 806, paper was being made in nine different Japanese provinces (Hunter 1947). The Imperial papermaking guild, the Zushoryo, once supplied only the Royal family. During a decline of the central administration, other lords attracted papermakers away from the slave-like domination of the guild, leading to widespread production. Papermaking was brought from Korea to Japan, in the same way the use of Chinese characters were introduced into Japan as a writing system. Previously, it was thought that papermaking reached Korea as early as the 2nd century, yet the oldest archaeological example of paper was from the 8th century (Library of Congress 1968). A recent find of paper at Koguryo (37-668) pre-dates the previous find (Bloom 2001).

The basic method of early Asian papermaking involved six steps that are illustrated in Figure 1. First, the pulp material was selected, and then beaten and scraped until it was of the correct consistency. Next, this material was placed in a large vat then boiled or fermented and re-beaten, breaking the fibers down, until it reached the correct consistency for pulp. One of two ways would be selected for spreading the pulp into the sheet mold. In the first, older method, enough pulp for one sheet of paper was placed into a mold, which would be dipped into a vat slightly below the waterline and gently shaken to distribute the pulp evenly. In the second method, the masticated pulp was directly placed into the water in the vat, creating a slurry. Then, the molds would be dipped in, collecting a layer of pulp (Hunter 1974; Bloom 2001). This was more efficient than the earlier method, and could be conducted on a larger scale. The molds were drained, and placed into the sun to dry or hung on a wall. Originally, molds were made of woven bamboo slats, while later sheets of silk or felt were used. After drying, the dried pulp, now paper, was smoothed on its rougher side by rubbing with a hard, polished object. In parts of Asia, paper is still made this way by small enclaves of paper craftspeople (Watkins 1992).

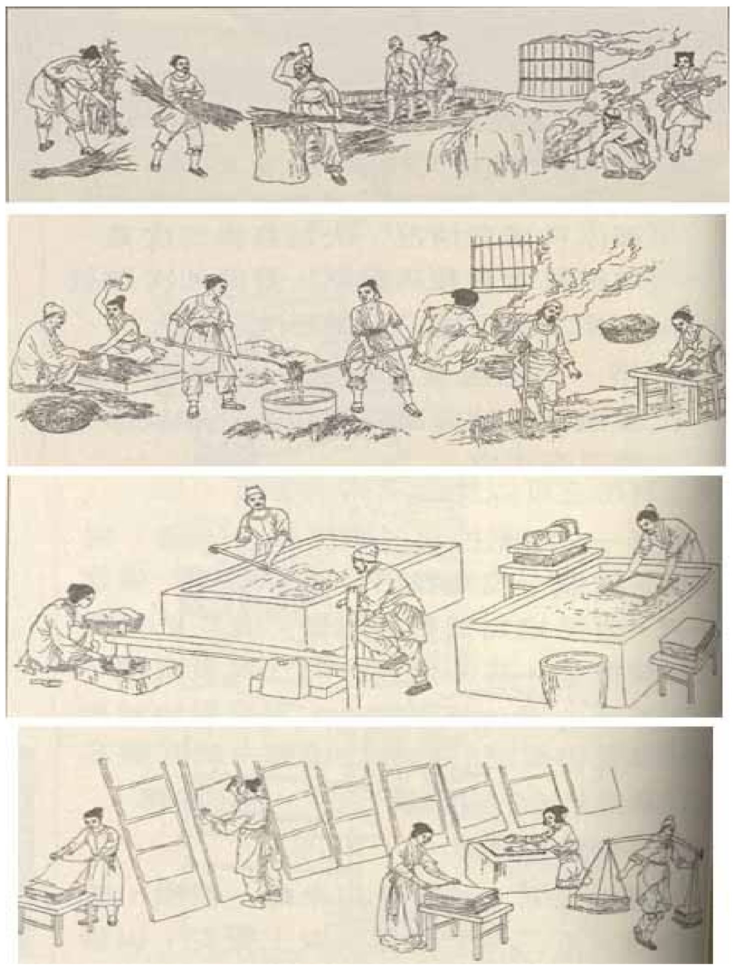


Figure 1. The woodblock images show the six steps of the papermaking process. From the 17th century *Thien Kung Khai Wit* or *The Exploitation of the Works of Nature* by Sung Ying-hsing.

The earliest example of a printed book, the religious text The Diamond Sutra, printed by Wang Chieh in 868, was found in Tun-huang, China. It is a single roll of paper sixteen feet long. This meant that they had molds and vats sixteen feet long at least, or were capable of end-joining paper seamlessly and undetectably.

In the 8th century, in a process very similar to modern surface coating, the Chinese began to apply gypsum, and later, an adhesive-like substance made from lichen to the surface of their paper (Garlick 1986). This gives the paper a more refined feel and brightness. The technique of surface coating is still in use and can be found on many papers today.

Western Asia and the Arabs

Hunter states that paper was first used in the Arab world in Mecca at 707 (Hunter 1947). An archaeological find of five letters dating to between the 4th and 6th Centuries demonstrates that paper was probably present earlier in what became the Arab world (Bloom 2001). By the 6th century, both Arab and Jewish merchants in Western Asia were actively trading with the Chinese Empire, so most likely, paper entered the Arab world, not as an independent invention, but as a rare trade good (Needham 1985; Rudin 1990). The date when paper began to be produced in the Islamic world is debatable. According to the Arab historian Abd al-Malik al-Tha'alibi, during The Battle of Talas in 751 in Samarkland, in Uzbekistan, many Chinese prisoners were captured by the Arab commander Ziyad ibn Salih (Bloom 2001). As the Arabs were deciding what to do with the prisoners of war, they asked if the Chinese had any skills. Apparently, they captured two papermakers, who were soon producing paper for their captors (Library of Congress 1968). Jonathan Bloom, in Paper before Print, the History and Impact of Paper in the

Islamic World (2001), suggests that this is just a story, and while Arab papermaking may have originated in Samarkland, it was the product of independent Central Asian papermakers, not prisoners (Bloom 2001).

Even if the Arabs copied the East Asian method of papermaking, they were unable to duplicate the material for their paper (Bloom 2001). Whereas the Chinese might use rags or other textile waste in their paper, Chinese paper was predominantly vegetable matter (bast, hemp, and other tropical plants not found in the semi-arid Arab world). So Arabs began using rags and became the first to make paper entirely from rags (Bloom 2001). This meant a change in paper production, as rags need different treatment than vegetable mater.

Historic Arab papermaking shares some affinities with its Eastern Asian origin, but the pulp was prepared differently, since it was mostly of linen fibers (Bloom 2001). The pulp material was moistened and fermented in heaps. Those heaps were boiled and either beaten using a trip-hammer, which was operated by treading on the levers (Hunter 1974) or a mill with hammers (Bloom 2001). Other types of mills were present in the papermaking area of Baghdad, including ship-mills- ships containing mills that were powered by the current (Bloom 2001). The pulp was placed into a vat, and sheets were formed using the hand-dipping process established in Eastern Asia. These were dried in stacks, and polished using alum and a burnisher. While the Arabs may have been successful in their paper venture at earlier times, Rudin states that by the fifteenth century, Arabs had begun to import "Frankish" paper from Italy (Rudin 1990). Apparently, the Arabs had not adapted their methods of papermaking in the ways that the Europeans did, and as a result the infidels' paper was better made and more desirable (Rudin 1990).

Africa and Europe

Paper was brought from Asia to Africa during the 9th century. It replaced papyrus as the dominant writing material by the 10th century (Needham 1985). Following the conquest of Morocco by the Arabs, Fez became a papermaking capital (Needham 1985). When manufacturers realized that interest in papyrus was waning, rags became a treasured raw material.

From the 11th century onward, Arab-made papers were exported throughout the Byzantine Empire and Christian Europe (Garlick 1986). Scholars think in 1150, papermaking was introduced into Arab-controlled Spain, establishing an industry in Xativa (Hopkinson 1978), and a stamping mill was in use there in 1151 (Hunter 1947). Since there are no archaeological references to support or refute the dates of European paper production, what is available are the few historical references to paper production or the origin of the surviving paper. As a result, some of the dates for the spread of paper production around Europe are somewhat skewed. Table 1 outlines the dates that paper began to be produced in Europe. Many of the Spanish papermakers were of Jewish heritage, and the industry in Spain collapsed during the persecutions of the Inquisition (Bayley 1965; Rudin 1990).

The first mention of an Italian paper mill refers to the mill in Fabriano, Italy in 1276 (Hunter 1947; Needham 1985). Credit is generally given to Pietro Miliani for establishing it (Garlick 1986). The Italians at the Fabriano paper mill introduced two important landmarks of paper production: the watermark in 1282 and animal gelatin sizing in 1337 (Hopkinson 1978). It is still in operation, making it the oldest operating paper mill in Europe.

Scholars think that the first French paper mill was established by Jean Montgolfier. He was taken captive by Saracens in the Second Crusade and forced to labor in a Damascus paper mill (Needham 1985). While prisoner, he spent three years learning the craft. In 1157, upon his return to France, he set up a papermaking establishment in Vidalon (Hunter 1947).

Table 1. Earliest dates of the first paper producing mills in European nations.

Country	Year
Spain (Xativa/Culhaucan*)	1150/1580
France (Vidalon**/Herault***/Troyes)	1157/1189/1348
Italy (Fabriano)	1260
Germany (Nuremberg)	1389
Switzerland (Marly)	1400
Belgium	1407
Holland (Gennep)	1428
Great Britain (Herfordshire)	1488
Poland (Krakow)	1491
Sweden (Motala)	1532
Denmark	1540
Russia (Moscow)	1690

* First mill established in the New World in New Spain (Mexico).
** It has been recorded that an even earlier paper production factory/mill had been established in France, by a former Crusader (Second) named Jean Montgolfier, who had been taken prisoner and forced to work in a paper mill in Damascus.
***The mill at Herault has been used by several scholars as the first mill in France, but this has been proven false due to a translation error (Hunter 1947). Additionally, its premise is illogical if paper making spread overland from the Arab world, as most scholars believe.

By the 16th century paper production was widespread across Europe. Even though paper was invented half-way around the world, the Europeans provided most of the inventions and innovations that are in use today, as well as some of the more interesting social adaptations to paper and papermaking. In 1540, the glazing or pressing hammer was introduced in Germany, which replaced the Asian style of burnishing the paper by hand (Hunter 1947). After 1600, paper was in such demand that the raw materials used in European paper production, notably rags, became very scarce. Rags became an individually-traded commodity with sellers and buyers. In 1666, in England, paper was in such demand by that a law was passed prohibiting the burial of the dead in linen or cotton, to save those materials for use in paper (Hunter 1947). The dead could only be buried in wool, which must have been a boon to the wool producers as well. This edict was thought to save 200,000 pounds of linen and cotton annually.

Initially in Europe, paper mills had to be placed near fast-moving water to operate the stamping mill. As the water wheel turned, it activated the cogs attached to each hammer, to cause them to pound numerous shallow tubs filled with rags and fibers. One pound of rags required one-hundred times the water to beat them (Hopkinson 1978) and some estimates run up to three hundred times (Corte 1980) using old mill methods. In the 1680, the Dutch invented the Hollander beater, which ground the pulp using slow moving water, windmills, and oxen driven mills, lowering the amount of water necessary to process pulp (British Association of Paper Historians 1999). It effectively ground the pulp, and is still in use among some Dutch makers. As the mill turned, it drove a roll, with teeth on the exterior to grind the paper against another surface (Schlosser 1979).

In 1719, French writer Rene Antoine Ferchault de Reaumur suggested the use of wood pulp to make paper after studying the processes used by wasps to make their nests. While he was the first to propose such a concept in Europe, it would be years until the process of pulping wood would be efficient. Prior to this and continuing into the 18th century, the bark of the paper mulberry was used in the pulp of Chinese papers. Jesuit missionaries suggested its transplantation to France (Needham 1985).

The first papermaking machine was invented by Frenchman Nicholas Louis Robert in 1799. His design was not successful and as the French Revolution was heating up, he did not get the opportunity to make refinements (Hopkinson 1978). However, his drawings were brought to England by John Gamble in 1801 and passed on to the brothers Henry and Sealy Fourdrinier, who financed the engineer Henry Donkin to build the machine (British Association of Paper Historians 1999). The brothers got little compensation from the machine when it was perfected, as it was easily copied. The only recompense is that it is still called a Fourdrinier. The first successful machine was installed at Frogmore, Hertfordshire, in 1803. While the pulping method was essentially the same as with hand-made paper using a Hollander beater, the paper was pressed onto an endless wire cloth, transferred to a continuous felt blanket and pressed again, it would have been cut off the reel into sheets and loft dried in the same way as handmade paper from this time (Rudin 1990). In 1809, John Dickinson patented a machine that that used a wire and cloth covered cylinder revolving in the suspended pulp, after which the water was removed through the center of the cylinder, and the layer of pulp removed from the surface by a felt-covered roller (later replaced by a continuous felt passing round a roller). This machine was the forerunner of the present day cylinder mold or vat machine, used today for the production of paper boards. Both the Fourdrinier and the Dickinson machines produced paper as a wet sheet, which required drying after removal from the machine, but in 1821 T. B. Crompton patented a method of drying the paper continuously. It used a woven fabric to hold the sheet against steam heated drying cylinders. After it had been pressed, the paper was cut into sheets by a cutter fixed at the end of the last cylinder (British Association of Paper Historians 1999). Many improvements have been made on the original machines, but these are the basic inventions that led to total mechanization of paper production (Rudin 1990).

New World

According to the Spanish survey of the New World, Relación del pueblo de Culhuacán dust Nuevo Espaňa (1580), the first paper mill in the New World was established in Culhuacán, Mexico. Hernan Sanchez de Munon and Juan Cornejo were granted a royal deed in 1575 for 20 years to make paper out of whatever material that they found there. There are no remains left of the mill (Hunter 1947).

While the first printing press in the British Colonies was established in 1638, the first paper mill was not established until 1690, by William Rittenhouse in Germantown, Pennsylvania. Rittenhouse, a German, had previously been a papermaker in Holland, before he brought his skills to the New World. Other early American papermakers include Benjamin Franklin, William Bradford, and Thomas Gilpin. Gilpin built the first papermaking machine in the United States, and received patents for it in 1816 and 1817

(Library of Congress 1968). The only equipment that survives of these early American mills are a few, battered molds used to form the paper, held by a few collectors. None of the buildings or equipment has stood the test of time and innovation (Hunter 1947). Hunter believes that it was the Americans quick adaptations to new papermaking technologies that allowed the earlier pioneers of the past to be swept away without a moment of hesitation (Hunter 1947).

Mechanized Paper Production; the Age of Paper

The contemporary paper industry makes trillions of dollars in profit (PricewaterhouseCoopers, LLC 2009) and production has been refined to an art at its most efficient. Several academic research agencies concerned with paper production exist, such as the Department of Wood & Paper Science at North Carolina State University and the Institute of Paper Science and Technology at the Georgia Institute of Technology, to name a couple in the United States, and many more exist world-wide. These institutions study every aspect of production from the actual machines to specific formulas of paper components, all seeking to discover new methods to increase efficiency and lower production costs.

Historically, mechanization was made possible by two major inventions: the paper making machine, invented by J.N.L. Robert and further refined by the Fordriner brothers and the use of wood pulp, a cheaper and more available resource than rags. During the 18th century, papermakers were beginning to group together into manufactories, to be able to make paper more efficiently. The result of this led to larger mills that were able to afford mechanization, and whose efficiency led them to look into alternate pulp sources, including renewed interest into wood pulp.

Other advances followed the implementation of the original machines, but they were essentially modifications to the original design. During the 19th century, these early innovations included machines that filled wire molds transported on endless chains, which were then placed or couched on continuous felts, creating one long sheet of paper. Then, a dryer section was introduced, which made it unnecessary to provide space and time for air-drying. Next, came a widening of the paper web (in one, case the width increased from 85cm to 770cm), mechanized cutting of sheets, and an increase in production speeds (Confederation of European Paper Industries 2011).

Industrialization drove out small operators who were not willing or able to afford the bigger and newer machines. By 1860, all parts of the papermaking process were mechanized, from rag preparation to drying and cutting of sheets. Production speeds increased with industrialization, since the average speed of production in 1820 was five meters per second, while in 1930, the average speed was over 500 meters per second (Confederation of European Paper Industries 2011).

Since 1950, industrial paper advances have been made in its chemistry, and not in the mechanics of the machines. New methods in bleaching and additives have allowed paper to become of a better quality and more plentiful for less money. Also, papermakers have become more aware of their impact on the environment and have enacted measures limiting their impact. And while big industry does dominate the market, there are still small paper producers that specialize in particular paper styles and types. These are craftsmen and artists producing beautiful papers, but the majority of paper products we encounter in our daily lives are manufactured by industrial papermakers.

Industrial Production

There are three basic steps involved in mechanized paper production: pulp preparation, wet-end, and dry end, illustrated in Figure 2. Wet-end refers to wet processes, like filling the molds, as opposed to dry-end, like the drying cylinders. The first step in making paper is to decide on the types of fibers to be used in the pulp and to locate a source. Frequently, paper mills will have a pulp mill nearby, but some do buy pulp from pulp mills that are not associated with the paper mill. In modern industrial papermaking, pulp is usually made from wood fibers. The pulping process is conducted one of three ways: mechanical, chemical, or a combination of both. Mechanically-pulped wood still retains its lignin and other natural products, referred to as groundwood pulp. If heat is used in the groundwood pulping process, the resulting pulp is called thermomechanical pulp. If chemicals are used with the mechanical process, it is called chemimechanical, and if both heat and chemicals are used with mechanical pulping, it is called thermochemimechanical or chemithermomechanical pulp. Paper from mechanically pulped fibers is used to make newsprint, magazine paper, and other items like boxes and paperboard. Since this paper may not be white in appearance, it is often whitened using hydrogen peroxide, if necessary (McCrady 1998).

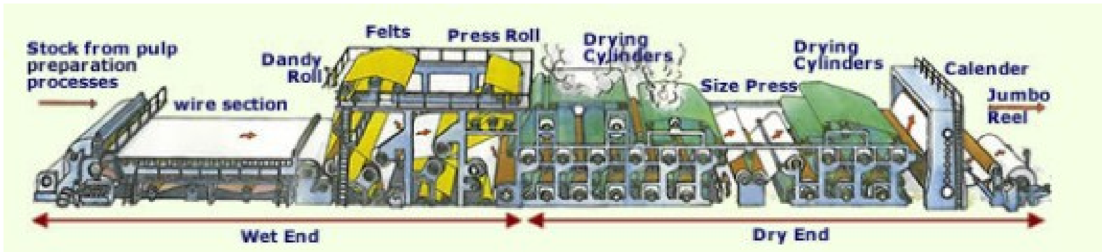


Figure 2. Model of a papermaking machine. Wet-end vs Dry-end paper production. Image used by permission of The Confederation of Paper Industries, 2010. http://www.paper.org.uk/information/process/machine.html

There are two main types of chemical pulping, Kraft, an alkaline method or Sulphate, which can be either acidic, neutral, or alkaline. Both are used to remove the lignin and other potentially damaging components in the wood pulp. The Kraft pulping method removes most of the lignin from the pulp, though the use of sodium hydroxide and other bases, and is most commonly used. Even if an alkaline method is used in pulping, this does not ensure that the paper itself will be alkaline. The Sulphate method seeks the same goal of removing the lignin, but is less frequently employed. In order to derive the most lignin-free pulp for a more lasting paper, the wood chips are heated under pressure using the chemical method. These forces must be carefully controlled to have a minimal effect on the cellulose, because without fiber strength, it will not make quality paper (McCrady 1998).

After a pulp has been selected, it is introduced to the papermaking machine. The mechanism for papermaking and its variables, while separated into wet- and dry-end, can also be separated into two types; furnish (pulp composition) and formation (manufacturing). Furnish variables include the types of refining, the fiber sources and chemistry, the dimension (length, width and fibril angle), furnish composition (ratio of fiber types), sizings, fillers and coatings. Formation variables include the extent of beating, fiber direction, basis weight, wet pressing, drying, fiber distribution, and calendaring (Dwan 1987). These are both wet- and dry-end forces, and tend to be mechanically derived, rather than chemical.

The last phase in pulp production is refining of the pulp or beating, to use the old term, while refining, is the term preferred now. Refining and beating are sometimes used interchangeably in describing this step in paper making (Browning 1977), but refining can include adding additional chemicals to the pulp. The earliest mechanization used water wheels to power hammers to beat rags into pulp. This was replaced by the Hollander beater, which employed knives, instead of hammers, and needed far less energy for operation. Different designs have come into favor, including cylinder, conical, and disc refiners, but the basic idea remains the same (Corte 1980). It was thought the type of paper was decided during the use of the beater, but now it is now thought that the refining process defines the type of paper produced (Emerton 1980b). It is at this stage that the additives are introduced into the pulp. These additives have a major effect on the end type of paper.

Refining impacts the physical and chemical structure of paper, and develops certain characteristics within the wood fiber necessary for paper production. The process involves the circulation of the fibers through a system that exerts both mechanical and hydraulic forces altering the fiber characteristics. In his book, The Chemistry of Paper (1996), Roberts states, "The most important change occurring during refining in terms of its effect upon paper properties is the change in the internal structure of the cell wall," (Roberts 1996: 79). The combined mechanical and hydraulic forces of refining allow the fibers to become more flexible, and flocculation is made possible (Conte 1980). Flocculation is the action that promotes fibers or particles to group together. Flocculation does not work by simply causing large fibers to collect other fibers by surface tension by forming a dam or impediment of sorts to the movement of other fibers. It can result from the addition of positively-charged additives, such as those of aluminum in alum, which attract negatively-charged paper fibers (Radvan 1980). During refining some of the fiber lengths are shortened. While one would think that longer fibers would mean stronger paper, long fibers tend to flocculate into larger groups, causing problems in the machines (clumps that get bigger and bigger until they break off) and in the uniform quality of the paper being produced. Cotton fibers, which are long by nature, if not shortened, can easily cause these problems, and be visually seen in the final paper (Emerton 1980b.).

Once the pulp is refined, it is ready to enter the wet-end papermaking and begin the formation of the paper from the pulp. A quantity of pulp and water is deposited onto the "wire table" (in the old machines these were usually woven wire grids, but now they are often polyester-based). Initially, gravity is the only force used to drain excess water and form the sheet. During this operation, as the water is removed, the sheet loses its mobility becoming more solid in its appearance. After the initial gravity draining of the excess water, further draining is assisted by "vacuum boxes" to remove the excess water from the pulp stock (Rudin 1990).

There are three types of water defined in paper making, categorized by their method of removal. The first is free water, which is the excess water that saturates the structure. It is easily removed by gravity and suction as described above in the second phase of wet-end papermaking. The second is capillary water that is held in place by surface tension between fibers and requires more force, such as pressing, to remove it during the third phase. The most strongly held water by the paper sheet is the water that has become bonded to the paper molecularly by hydrogen bonds. This often requires thermal forces for removal during the dry-end process, such as heated drying cylinders (Emerton 1980b).

Then the pulp sheet may continue to an area that applies a light pressure from a "Dandy Roll." The Dandy Roll was invented in 1825, and is the first step in pressure applied to the sheet. These rolls often have watermarks applied to them, which when applied to the sheet, leave behind a slight indentation. The Dandy Roll acts as a gentle press, forcing the water in the top layers of the sheet to flow in the direction opposite to that of the web of paper. This is the first light "crushing" of the paper. If great force was exerted when the paper matrix was still so waterlogged, it would create ruptures in the sheet (Radvan 1980). But if it does not encounter a Dandy Roll, it moves on to the couching felts and the press roll, which remove water though the application of external forces, forming a pseudo-plastic mass (Rance 1980b). This is the third phase of the wet-end. The paper is strong enough to support itself going to the wet presses, where additional water is pressed out by fabric or polyester covered rolls (Rudin 1990).

The operation of the machine itself has an effect on the paper, beyond simply laying it down and drying it. Changing the machine speed during the wet-end stage alters the fiber orientation, resulting in different strength properties, especially in the machine-direction (parallel to the motion of the machine) and the cross-direction of the sheet. Additionally, various pressing conditions alter the density, porosity, optical, bonding, and strength values (Dwan 1987). The result of these forces is that the machine direction has a higher strength and less tensile stretch than the cross direction of the sheet (Radvan 1980).

The final stage of paper production is the dry-end. At this point, there is a compaction of the elements, in one or more planar directions, and the qualities that the compression instills become set into the paper matrix (Rance 1980). The paper is pressed and dried by passing through a number of hollow, steam-heated drying cylinders, set in horizontal alignment overlapping each other. The paper may pass through some cooled drying cylinders as well, since a humidity content of about 50% is desired (Rudin 1990).

After leaving the drying cylinders, the paper moves onto the calendaring rolls. These may be composed of sizers and press-rolls. Calendaring affects surface and strength properties (Dwan 1987). It is the papermaker's last chance at altering the properties of the paper (Radvan 1980). Machine calendaring is carried out on most machines between the last dryer and reel-up. Calendars are comprised of a vertical stack of smooth surfaced iron rolls that the paper passes through to smooth it. The rolls may be heated or cooled. There are several purposes to calendaring. It is the last chance to override any imperfections in the paper left behind in the process. It can literally iron-out any imperfections to ensure that it goes to the reel successfully. Calendaring does cause some damage to the sheet, as it can place too much compression on areas that are high spots (thicker) in the paper, weakening them. There are positive effects of calendaring as well. An uncalendared sheet is usually too rough or uneven for quality printing, while calendaring smoothes it enough to be able to be coated, generally improving the surface of the paper with additional optical properties, such as gloss (Radvan 1980).

After undergoing all of these different processes, that which was wood pulp has been transformed into a roll of paper. The machines and processes described here have provided a condensed outline of the process of mechanized paper production, covering the basic equipment and formation processes involved. While the steps involved in both hand-made and industrial papermaking vary, they directly affect the properties of the individual sheet.

Material Culture

The previous sections in this chapter provide an account of the history of paper production and its technology. But why is it important to conserve and preserve paper, especially now since we can copy or digitize any writing, image, or text so easily? Simply put, digital copies are not the same as having the original to study. Without the paper artifacts of material culture, it is impossible to acknowledge or gain an understanding of the culture or the individual who created and modified the paper. The rest of the chapter is devoted to a discussion of the material culture of paper, providing the basis for the need of the conservation and preservation of severely damaged paper.

The first person to use the term "material culture" was Stewart Culin, Curator and then President (1897), of the American Folklore Society. He used "material culture" in contrast to the "antiquities" of the archaeologists (Bronner 1992a and 1992b). Fundamentally, material culture is all of the artifacts and landscapes that have been modified by man according to traditional patterns resulting from learned human behavior. Material culture is the sum total of the items that are made or modified by humans, consciously or unconsciously, that reflect the ideas of the creator based upon concepts that have developed over time, and reflect the belief patterns of the society at large (Schlereth1985a and 1985b). These can be used to deal with the physical world, facilitate social interactions, aesthetically amuse, or create symbols (Schlereth 1985b). The best summation comes from Henry Glassie, who in his work, Material Culture, states, "Material culture is culture made material; it is the inner wit at work in the world. Beginning necessarily with things, but not ending with them, the study of material culture uses objects to approach Human thought and action" (Glassie 1999:41). Artifacts recall the technology by which nature was made cultural, as they are the embodiment of the idea in the maker's mind, containing all of the decisions used in their making (Glassie 1999). Material culture is made up of the tangible things crafted, shaped, altered, and used across time and space; it is how these objects weave themselves through the everyday lives of people and communities (Bronner 1986). James Deetz, in In Small Things Forgotten: The Archaeology of Early American Life, saw material culture as “that segment of man’s physical environment which is purposely shaped by him according to culturally dictated plans” (Deetz 1977:24-25). In Thomas Schlereth’s article “Material Culture and Cultural Research” from Material Culture: A Research Guide (1985b), he states that, “Material culture is that segment of humankind’s biosocial environment that has been purposely shaped by people according to culturally dictated plans” (Schlereth 1985b:5).

The study of material culture is the foundation of understanding a culture from an artifactual perspective. Glassie states, “The study of material culture is the study of creativity in context” (Glassie 1999:67), meaning the creativity of the individual(s) within the culture. Artifacts provide the connection of social and individual realms to the function of objects, past and present. Since they are mute, objects speak through the lives that experience them, and because of their muteness, we are drawn closer to the objects to sense their meaning as they must be interpreted (Bronner 1986). Every person uses, makes, and modifies things. We surround ourselves with objects and symbols deliberately selected according to our own needs. As Bronner states in “The Idea of the Folk Artifact,” from American Material Culture and Folklife (1992), “All objects need to be known for the lessons they teach and the meanings they hold” (Bronner 1992b:36). The artifacts of the past can provide a different perspective on a group than written records. Oftentimes, the common man is left out of the historical or written record, but through the material culture of the day-to-day life, his existence can be better understood. Since culture is cumulative, every experience can leave an imprint on a society. Some would argue that historical documentation provides more information about a culture then could ever be learned from an artifactual perspective, but material culture studies demonstrate that that is not always true.

Glassie believed that when documents accompany artifacts, it would be foolish to disregard them, but they should not take the place of what the artifact has to say. He saw that it was wrong to believe that there is more to learn from the document than from an artifact. They both need separate analysis, followed by comparison and contrast. An artifact is a text itself, which displays both form and a vehicle for meaning (Glassie 1999). A story or written report moves in a temporal experience, moving in one direction accumulating associations over time. An artifact is a part of the special experience, moving in all directions at once, embracing contradictions, and opening different definitions of significance (Glassie 1999). There is a movement within material culture studies to look past “dusty documents and fleeting words” to the objects for revelations about the past (Bronner 1992a: xxvi). The written word is not descriptive enough, as not only is ‘seeing believing’ but it is touch that can evoke the most response. Like Doubting Thomas having to not only see, but feel the wounds in Jesus’s hands, by touching and seeing the artifact itself it is made more real to the observer (Bronner 1986). People respond to words, but the objects that they grasp have more lasting things to say (Bronner 1986).

In the past, some folklorists, anthropologists, curators, and conservators have not paid particular attention to paper as an artifact. Paper only receives attention when is seen as an important document or as a medium for a work of art, which is certainly significant, but does not incorporate other types of artifactual paper. The paper itself is not seen as to be important as an artifact; its only import is as a medium to convey a written or printed message. Additionally, when paper has no message or art upon it, it is not considered significant, and is secondary to paper conveying a message. This should not be the case.

The reverse can be true in material culture studies. Paper as a medium for art and paper artifacts not used for writing are more easily classified as material culture. Paper with writing upon it is sometimes not deemed a part of material culture, as it is too overtly descriptive, and provides an inherent bias in interpretation. But paper is a category of material culture, regardless of whether it has writing or other media upon it.

Early historic papers are carefully handcrafted artifacts. Skill was used in their creation and the individual signature of the creator, seen in the watermark or the particular size of the mold, can designate it to a particular individual's craft. This individualization of creation seems to be one of the prevailing principles in designating an artifact as a part of the folk culture of an area.

There is much material culture data that can be learned from early historic papers, other than the skill level of the producer. The earliest paper, such as that from China, is an important example of a developing technology. The spread of paper across Asia, and its subsequent improvements and changes, can demonstrate how technology moves over time, from its source to outlying areas that change methodologies due to lack of materials, but still end up with a similar end product. Interesting concepts about trade and trade secrets can be discussed, not to mention the obvious movement of ideas and art forms via the messages on the paper. Yet, not only was "used" paper being traded among these groups, but blank sheets were moving, as well as objects made of paper, like lanterns and screens. The number of people who were interacting in papermaking, selling, and transporting paper would have to be fairly numerous, as the demand for a light-weight recording device would be high, not to mention, as a product to be used for other purposes. Also, other similar industries, like the papyrus and vellum industries, would inevitably react to the influx of this new medium and regard it as a threat. So many things can be learned from an old piece of paper!

Modern machine-made paper should be acknowledged as an artifact as well. This category is harder to define, since it is mass-produced, so it cannot be defined as a folk item or the work of an individual or small group of creators, lavished with detail and personal attention. But it is still material culture. While the mass-produced items do not leave a conscious signature of the producer, they are a part of most peoples' everyday lives, and therefore should be granted material culture significance. In the historical record, it is the day-to-day mundane that is often the least recorded, yet occupied the most time of the historic individuals.

To generalize, three types of paper categories exist: paper in the form of a document, paper in the form of art, and paper used for a different purpose (a thing not serving for direct communication through the written word or media expression). While each group of paper had a designated use, it expresses both overt and covert meanings, and should be considered an artifact of material culture.

The first category of paper, paper used for documentation or other transmission of the written word, is the most easily dismissed as not being an artifact. Its value does not lie in the paper that it is printed upon, but in the text itself. As a document, paper is invaluable to the historian and researcher. Yet, the paper itself is seen as the medium of expression, simply passed over in importance. If this is truly the case, why bother to conserve paper at all when we could just reprint or digitally record the original? Is it just for the evidence of the original message? Why should we, the American public, spend millions of dollars to rehouse the Declaration of Independence or go to view it? We all know what it says and who signed it. The fact is that the paper itself is a souvenir, which denotes the special moment in time that the artifact symbolizes (Bronner 1986). The Declaration of Independence is an artifact of the historical moment of its creation and it was handled by some of our great American patriots. Or hypothetically, what if it was blank, but it was known that the paper was the overlying sheet that would have been handled by all of the signers, would it be worthy of preserving? Would this make it any less a part of the material culture from that era, any more so than the desk Thomas Jefferson sat at to write it? Of course it would be worthy to preserve and no more so than Jeffereson's desk.

We have all heard, "don't judge a book by its cover," but we should do just that. There is material culture data to be derived from a book just being a book. Bronner refers to his book as "a social artifact" (Bronner 1992a: xxvii). The creation of a book as a material culture item does not only mean the writing text, as other features impart information. The deliberate selection of a specific paper by the printer demonstrates a conscious choice in the creation of the book. The style of type font is a specific choice based upon a concept within the mind of the printer, or even the input of the author, limited by which type or typesetting was available. The materials in the binding were chosen by a skilled craftsperson or an engineer for a specific purpose. And the cover has a specific image or lack thereof on the cover and spine. The same is true for an individual page of text. The words have meaning, but the selection of all of the materials used in writing, from the type of pen to the size of the script, provide data.

The second category of paper, paper used in art, provides cultural data as a whole and as a sum of its parts. Without attempting to define art, an ethereal and undefinable construct, it is a creation full of material culture data. Even though the paper is the medium for the expression of ideas, it is deliberately selected for its specific traits by the artist. Size, thickness, color, quality, strength, and expense are qualities one uses in selecting what type of paper to use for a specific job. Paper has its own limitations, which are accepted by the artist in their creation. The stone a stone cutter uses in the creation of a grave marker is as much a part of determining the type of carving, and therefore the finished product, as the artist himself (who admittedly does contribute more). Artist intent must take into account the type of paper used in the creation of his vision. When a group of schoolchildren make letters to be placed at a memorial shrine, each child selects a piece of construction paper of whatever color they desired, they decorate it individually, and express their own emotion for people they probably had never even met. The children created things, messages, artifacts, and manufacts. If it was simply the message that was important, plain white paper and a rewritten statement would have been sufficient. But the children created out of their own ability to express their own message of sadness and sympathy.

The third category of paper, anything not considered art or documentary, is easiest to define in terms of material culture. It does not have overt messages upon it, and its purpose is independent of the usual paper forms, and should be easily accepted as a part of the material culture of that culture. During the excavation of the artifacts of the La Belle shipwreck (1687) by the Texas Historical Commission from Matagora Bay, Texas, the remains of several trade knives were found wrapped in paper. This unique discovery of paper artifacts from this period was perhaps even more important as a material culture artifact than the knives themselves. Metal knives would have been expected on the ship, for both use and trade. Yet, who knew that they were packed so carefully and deliberately in individual paper bundles? How much wrapping paper from then or any era has survived? It is a part of the time capsule of the moment, and in order to get to the behavior behind the artifact, it is necessary to understand the nature of the artifact. Artifacts convey their meaning without words, and are not defined by the words written on them. Paper conservators, library scientists, and bibliophiles have always understood to an extent the need and the value of the original document, instead of a facsimile. What they and so many others do not acknowledge is the paper itself, sans writing, holds a message. Therefore, it is imperative that paper be accepted material culture category by those who attempt to understand the behavior behind the artifact as.

Conclusion

This chapter surveyed the creation of paper and its potential uses and interpretation. The history of its invention demonstrates how an idea can be made real in one place using a specific set of components, which evolve and become refined as the idea moves through time and space. The changes in papermaking materials and technology directly affect the types of paper produced. Yet, it is not enough to understand the technology over time to grasp the full meaning of paper.

Without the paper artifacts of material culture, it is impossible to acknowledge or gain an understanding of the culture or the individual who created and/or modified the paper. It is not enough to simply acknowledge the methods of production or replicate the messages on the paper to preserve the meaning of the artifacts. Paper artifacts are an important part of the material culture of a paper utilizing society.

CHAPTER III

CHEMISTRY OF PAPER

Before undertaking the conservation of paper, it is necessary to consider the chemistry of the material. This chapter provides an overview of the chemistry of paper. Paper is a complex artifact, with many different possible combinations of components and ingredients. Taken in combination with effects of manufacture, the final paper matrix is highly variable. Paper is not as easy to define chemically as a stone artifact, but even that requires an understanding of the chemistry and geology involved in its formation. Since papermaking, both historic and modern, has been generally discussed in Chapter II, it is not necessary to elaborate on the mode of production, only on its physical and chemical effect on the finished product.

Prud'homme and Robertson state in their article, "Composite Theories Applied to Oriented Paper Sheets," (1976) that paper "is a composite material, although itself made up of other materials, can be considered to be a new material having characteristic properties which are derived from its constituents, from its processing, and from its microstructure" (Prud'homme and Robertson 1976:145). One would think that the variations in paper structure and composition are the result of the type of pulp, the additives, and bleaching, while the processes used in the making of the paper (refining, beating, rolling, drying, pressing, etc) would be uniform, resulting in compositionally similar paper. In point of fact, paper is more than the sum of its parts; the manufacturing process can have a large effect on the properties of the paper, as paper made from the same pulp, but undergoing different production methods, can result in very different types of paper (Dwan 1987).

This chapter will begin with an overview of pulp materials and interactions, and the effect that both hand-making and mechanization have on the structure within the paper. Various additives and bleaches used in paper production will be described. The result of this chapter will be an understanding of the molecular structure and strength of paper.

Paper is defined as, "…a sheet material made up of a network of natural cellulosic fibres which have been deposited from an aqueous suspension" (Roberts 1996: 2). Cellulose fibers can be derived from many sources including wood, composing the majority of paper produced today, and other fibers used around the world including bagasse, bamboo, jute, ramie, hemp, flax, and other various grasses, seed hairs (cotton), and straw (Browning 1977; Roberts 1996). Their advantage over wood is that they can be grown in areas that would not support trees, and can be harvested much more readily after planting than a tree (Dwan 1987; Bloom 2001). Historically, paper has been made from many different cellulose sources, including those listed above and other recycled materials, such as rags or old paper. The available materials dictated what was used in production, within reason (Hunter 1947). As paper is created from fibers of various plants and trees, its cellulose composition is neither fixed nor universal.

Of the many possible sources of cellulosic fiber, trees yield the highest proportion of fiber versus weight (Emerton 1980a). Since they have very different fiber morphologies, both hardwoods (angiosperms) and softwoods (gymnosperms) are used for making paper (Emerton 1980a). Fibers of softwoods are longer and stronger than those of hardwoods, and make up the bulk of paper-making fiber worldwide (Robert 1996). Unfortunately, they easily become tangled masses, and therefore, create sheets with a non-uniform distribution of fibers. A combination of the fibers is often used. Variability in fiber length can be produced within the same tree as a result of early vs. late wood, heart wood vs. sapwood, and additional changes can be found in other contaminates within the tree and the bark. This type of variability in fiber composition can also be found within other materials used in the making of paper, such as flax, cotton, grasses, hemp, and jute (Dwan 1987). Figure 3 is an Environmental Scanning Electron Microscope (ESEM) photo of paper and its fiber network that provides an example of the various fiber widths and lengths.

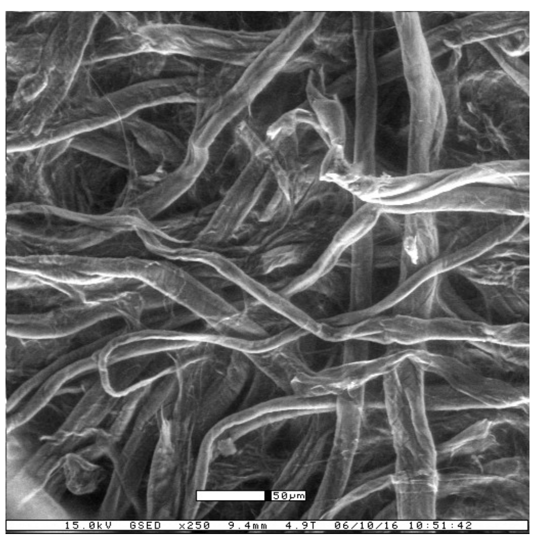


Figure 3. Environmental Scanning Electron Microscope (ESEM) image of paper fibers. All ESEM data was obtained at Texas A&M University on equipment purchased under National Science Foundation Grant ECS-9214314.

There are four distinguishable layers identified in wood fibers: the primary cell wall and the three parts of the secondary cell wall structure, which contain fibrils seen in Figure 4 (Dwan 1987; Roberts 1996). The primary cell wall is a membrane that surrounds the protoplast during cell division and enlargement, and where two primary cell walls meet is the compound middle lamellae (Emerton 1980a). Figure 5 is a magnified photo of a cross section of a piece of wood showing the individual paper cells, with the lamella clearly seen. When the fibers are free of the middle lamella, they are the individual fibers used in paper making. The combined mechanical and hydraulic forces of refining cause the cell wall to delaminate and create voids in which water can exist. This allows the fibers to become more flexible. The primary cell wall is made up of microfibrils that are widely spaced, interwoven, and bundled. The P layer is the

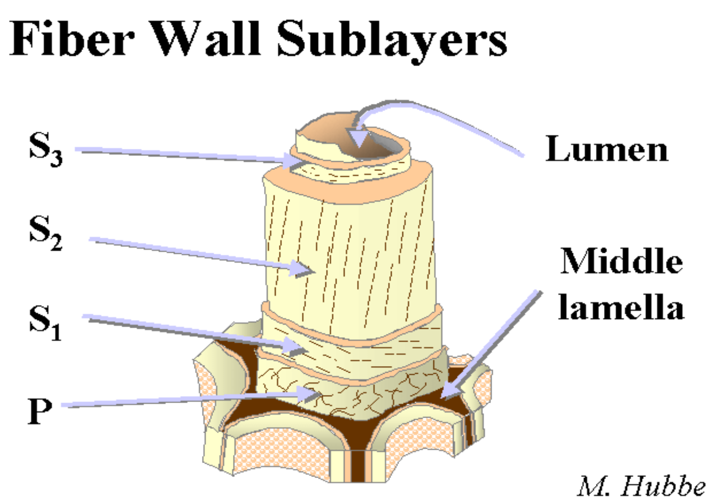


Figure 4. The sublayers in an individual wood fiber wall (Image courtesy of Dr. Martin A. Hubbe, Department of Wood and Paper Science, North Carolina State University, Raleigh, NC.).

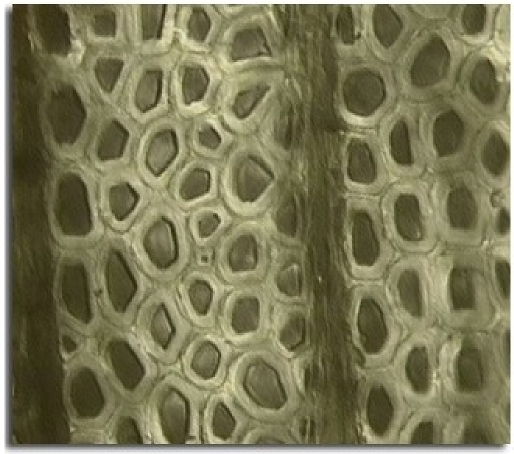


Figure 5. Cross-section of wood cells magnified. Photo courtesy of Dr. C.W. Smith, 2010.

primary cell wall and the secondary layers are composed several lamellae or membranes. The S1 cell wall is comparable in thickness to the primary wall. It is composed of four to six lamellae, which lie in opposing directions around the longitudinal axis of the tracheid. The S2 layer is the thickest of the layers (Roberts 1996). It is the dominant layer in the cell wall, and the angle of the fibrils in the S2 layer influence the individual fiber's physical properties and sheet properties. The fibrils are the small lines within the diagram. The angle of the fibrils is determined by their position in relation to the fiber (Dwan 1987; van der Reyden 1992). The angle is usually about 10-20%. The orientation of the fibrils in this layer have an important effect on the mechanical properties of the fiber, like its elasticity (Roberts 1996).

Fibrils running parallel to the fiber have a low angle, and therefore can withstand greater load, less elongation, and are stiffer, as opposed to these with high angles with fibrils running perpendicular to the fiber, which are more flexible (Dwan 1987; Roberts

1996). Figure 6 provides a better illustration of how the fibrils align to form the individual fibers of the paper, and how they are composed of individual chains of cellulose. Each of the fibrils are held together in fibril bundles by van der Waals force- a an attraction that holds surfaces together that are not molecularly bonded together (Murphy 1985). Each fibril is composed of microfibrils, which are composed of layers of cellulose chains (van der Reyden 1992). Each chain usually has between 3000 and 5000 units and can have up to 15,000 (Roberts 1996).

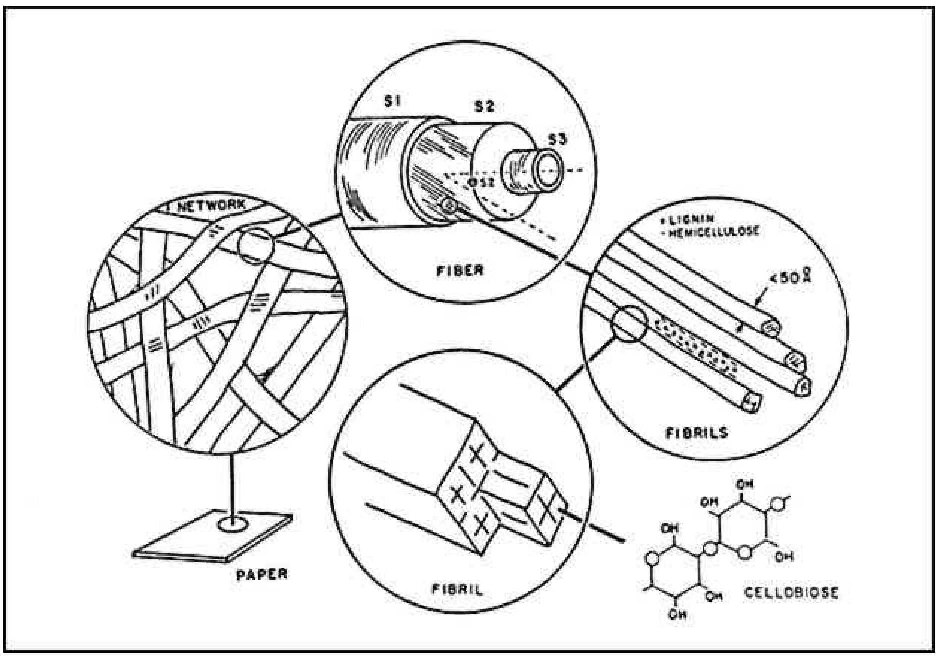


Figure 6. Fiber walls and fibrils. Note the orientation of the fibrils within each of the secondary cell walls. Image reprinted with permission from Dwan 1987.

On a cellular level, the cells of the plants and trees are mainly composed of carbohydrate polymers (polysaccharides) impregnated with lignin, a complex aromatic polymer. The main components of wood fibers are cellulose, hemicellulose, lignin and other trace materials. The overall molecular composition of the average wood is 50% carbon, 6% hydrogen, and 44% oxygen, depending on the quantity of lignin (Roberts 1996).

Cellulose is the primary structural component of the cell wall and paper. It is the most abundant form of living terrestrial biomass (Crawford 1981). Chemically, it is crystalline microfibrillar linear polysaccharide of β-1,4-linked polysaccharide of β-D-glucopyranose (Roberts 1996). Its structure is demonstrated in Figure 7. It is never found in a completely crystalline form, but is partly crystalline and amorphous material; the percentage of crystallinity varies between 50-90% depending on the source material

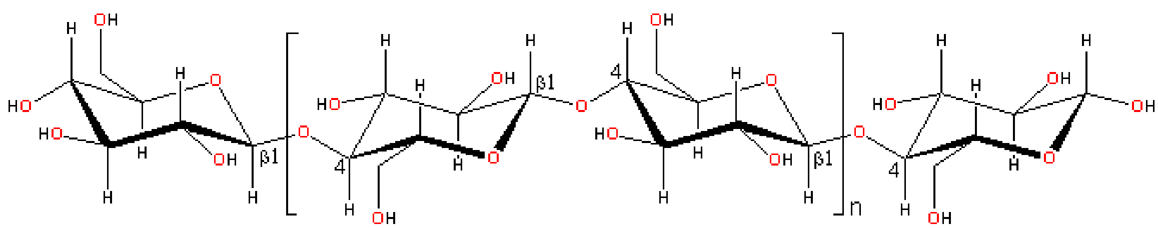


Figure 7. Molecular structure of cellulose.

and the method of measurement (Emerton 1980a; Dwan 1987; van der Reyden 1992; Roberts 1996; Sandy, Manning, and Bollet 2010). Figure 8 shows the possible alignment of fibrils and the crystalline and amorphous regions in the cellulose chains. It shows what happens to the structure during aging. Cotton is highly crystalline, while wood tends to be less so (Roberts 1996). The crystalline areas are more stable than the amorphous regions and provide tensile strength, but without the flexibility provided by the amorphous regions, the chains would be rigid (Emerton 1980a; Sandy, Manning, and Bollet 2010).

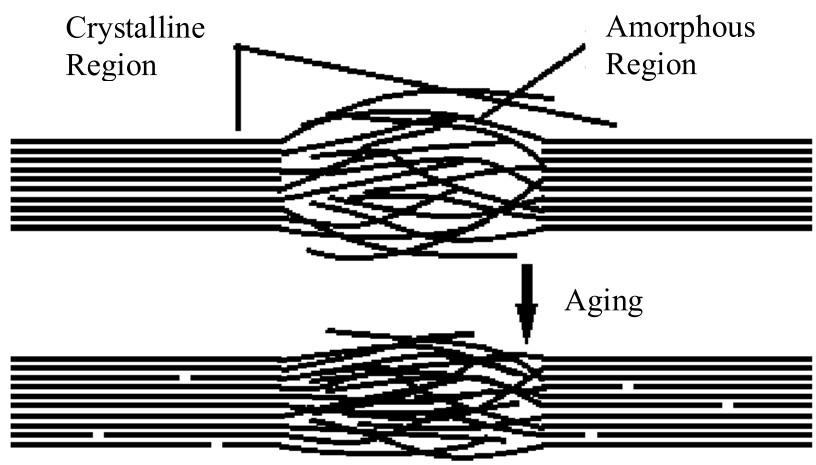


Figure 8. Detail of fibril showing the crystalline and amorphous regions in the cellulose chains with suggested aging structure (after van der Reyden 1992).

It has been established by X-ray diffraction that water does not enter the crystalline regions of cellulose during pulping or refining (Roberts 1996). As a result, water can only enter into the amorphous regions between the crystalline areas. Some solvents can penetrate the crystalline areas, but water cannot, and therefore it does not enter during the papermaking process (Roberts 1996). Numerous theoretical models have been proposed for the molecular organization of the amorphous and crystalline areas, as they are not completely understood (Roberts 1996; Sandy, Manning, and Bollet 2010).

Hemicellulose is a group of non-structural, low molecular weight polysaccharides that are unrelated to cellulose (Emerton 1980a). Hemicelluslose may be composed of many different sugar monomers, rather than cellulose, and are formed biosynthetically through a different mechanism. Hemicellulose may have some function related to water transport, but it is not entirely understood how it functions within the tree. It is too weak to be major structural components of wood, as their chains are only composed of around 200 units, yet, the tensile strength of paper generally correlates to the hemicellulose content (Roberts 1996). It is possible that hemicellose is absorbed into the fiber surfaces during pulping and refining, assisting in inter-fiber bonding (Roberts 1996). Even after chemical delignification, a substantial percentage of hemicellulose is left in the pulp. The only way to remove hemicelluloses is after the removal of lignin, as they seem to be covalently bonded via ester linkages (Corte 1980).

While trees provide the highest amount of cellulose by weight versus other plants, pulp from trees always contains lignin (Emerton 1980a). There are little to no desirable properties of lignin in papermaking. It comprises about 17-33% of the weight of dry wood (Emerton 1980a). It is a complex aromatic polymer, functioning both as a strengthening agent and as a component assisting in the prevention of decay and attack by micro-organisms within the living plant (Roberts 1996). It is not uniformly distributed through wood, and it seems to be concentrated in the inter-cellular spaces and in the cell walls, mostly in the secondary cell wall (Roberts 1996). Lignin forms a connecting matrix that holds together the cellulose fibrils (Emerton 1980a). Lignin acts as an oxidative presence and discolors, especially when exposed to light, high humidity, and air pollution, causing the paper becomes yellow and brittle. As a result, lignin must be removed from any paper which is expected to last over time (Roberts 1996). Lignin is not water soluble, so it is removed using alkaline, neutral, or acidic solutions during pulping, (Crawford 1981; Roberts 1996).

When the wood fibers are subjected to high heat and alkaline treatment during pulping, the cellulose and hemicelluloses undergo some changes from their original structure. Some of the carbohydrates are dissolved, especially the hemicelluloses, and some become shorter chains. The most degenerative effect from pulping is peeling, during which single monosaccaride units are removed from the reducing end of the chain. The end group contains a carboxylic acid functionality that has an influence on the anionicity of the fibers (Roberts 1996). Cellulostic fibers tend to be anionic due to the acidic compounds present, which may be carboxylic or sulfonic acids. Carboxlic acid groups come from a number of different sources. Acids lead to the hydrolysis of the cellulose chains, as seen in Figure 9, and can continue to further break the chains and cause peeling reactions. Alkaline degradation can produce carboxylic acid groups on the reducing end of the cellulose and hemicellulose chains, stopping reactions which stabilize the chain end to further degradation. They are introduced during bleaching or other oxidative treatments, and they may be present in hemicellulose. Sulfonic acid groups are introduced during the mechanical pulping by sulfite impregnation. As the pulping continues, the lignin content and other acids are reduced (Roberts 1996). After chemical pulping, the pulp is brown in color (usually the result of the remaining lignin [3-6%]), leaving it unsuitable for writing papers (Roberts 1996).

Both chemically and mechanically pulped papers are bleached after pulping. Mechanical pulps retain more lignin, so whitening them requires more processing, using

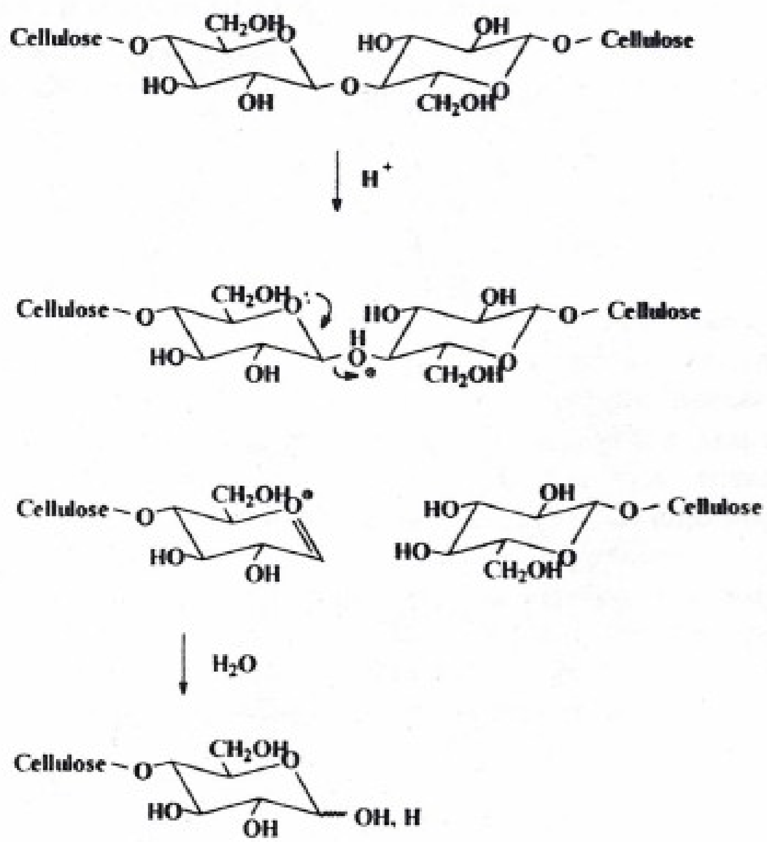


Figure 9. The hydrolysis of cellulose during acid pulping.

either reductive or oxidative processes. The reductive agents often used are bisulfite, dithionite or borohydride. The oxidative agents most often used are peroxide, hypochloride, peracetic acid or ozone. Bleaching chemically pulped papers mainly involves the removal of the residual lignin. Therefore, the lignin content of the pulp prior to bleaching indicates the amount of bleaching chemical necessary to achieve the desired result. Until recently, chlorine and other chlorine-based compounds were used as bleaching agents for chemically pulped paper. These methods included the use of chlorine in an aqueous solution or chlorine dioxide, in combination with alkaline extraction stages. Chlorine reacts very quickly with pulp and most of it is consumed with a few minutes. Unfortunately, these are environmentally damaging, so the industry is moving to the use of non-chlorine bleaching systems. The amount of bleach used must be exact; not enough, and the paper is discolored, and if too much is used, the physical strength of the fibers is reduced (Robets 1996).

Additionally, wood contains a small amount of other components (less than 5%), including alkanes, fatty alcohols and acids, glycerol esters, waxes, resin acids, terpene and phenolic components. Most of these components are removed during the pulping process, since they are either damaging or not necessary or desired components of the paper. Yet, some may be present in the finished product, depending on the process employed (Roberts 1996).

Once the pulp is prepared, the cellulose fibers are ready for the next stage in papermaking, referred to as refining. While pulping frees the individual fibers from their organic matrix, refining prepares each fiber for paper making. Paper made from refined fibers has greater strength, higher density, lower opacity, a smoother surface, and a more regular formation. In historically, refining occurred during the beating of the fibers to make them absorb more water. Mechanically produced paper is refined by placing the pulp ingredients into complex machines, along with other additives to prepare them for formation. Often, differently prepared pulps are refined together to produce specific papers, as the best pulp is made when it is a mixture of both types of fibers; long and short (Roberts 1996). According to Dwan,"Within each fiber type there are differences in cell length, fibril angle, cellulose content, lignin content, and extractive chemistry"

(Dwan 1987:2). Each of these characteristics is taken into consideration when the pulp is selected.

During refining, the pulps are placed into an aqueous environment, and the fibers are circulated to apply stress. This causes the primary cell wall to be further delaminated and allow water to be absorbed into the secondary cell walls. This allows the fibers to become more flexible, causing internal fibrillation (Roberts 1996). Some of the microfibrillar structures become loose, causing external fibrillation and an increase in surface area (Emerton 1980b.). Not only does fibrillation occur and fines (small chains of cellulose) are created, but there is a change in the curl of the fibers and a change in the number of nodes, kinks, slip planes, and compressions in the cell wall (Roberts 1996). Some fibers are shortened in the process, not by exact cuts, but by tensile splitting. Some soluble polysaccharides become redeposited on other surfaces. As it becomes more flexible, the structure collapses into the lumen, causing it to appear more ribbon-like. It is also possible that by exposing the inner layers, as a result of the removal of the outer layers, more areas become capable of greater hydrogen bonding (Emerton 1980b).

The major ingredient in early historic Western paper is the flax fiber, usually derived from linen rags and cuttings, but can be acquired from the retting process (Emerton 1980a). During retting, the flax plant is allowed to partially rot, permitting the removal of the flax fibers that vary from 15-100 cm long. The fibers are very strong, and have a very low quantity of lignin. The individual fibers are often waxy, which imparts a luster to linen fabric, but is an undesirable trait for paper making. Rags and fibers must be gently boiled and bleached to remove the wax. If this is carefully completed, there is no loss of fiber strength (Emerton 1980a). During the beating or refining process, the fibers are broken down into to fibrils of considerable length, producing very strong and durable paper (Emerton 1980a; Wooten et al. 1996). As the beating technology changed, even better fibers were harvested with less energy (Wooten et al 1996). Cotton became an important source during the 19^{th} century, making for even softer and regular paper (Wooten et al. 1996). While the initial morphology of these fiber types are different from wood fibers and its processing, the fibers are still composed of organic cellulose, and therefore behave in a similar fashion to wood fibers. The fibers from these source become bound together through both inter- and intra- fiber bonding the same way wood fibers become bound to make paper (Emerton 1980a; Wooten et al. 1996).

While the preparation of any fibers for the formation and type of paper produced is important, supplementary additives have a significant impact on the qualities of the paper. Papermakers use many different additives in the formation and finishing process to ease the formation of uniform sheets, and to impart specific qualities in the finished paper. One type of additive, fillers, are often added to paper during refining to improve properties that may otherwise be lacking in paper, and can been seen in Figure 10. Common fillers are kaolin and chalk, but talc and other pigments, such as titanium dioxide are also used (Emerton 1980a; Roberts 1996). These are cationic. In the past, the choices of additives was based upon trial and error; if the resultant paper looked and felt good, then that was enough. Now, we recognize that there are more processes at work within the paper itself, namely concentrations of acids. If paper is to last, additional oxidative agents should not be added to the “slow fire,” a term coined for the slow decay of paper as a result of internal acid.

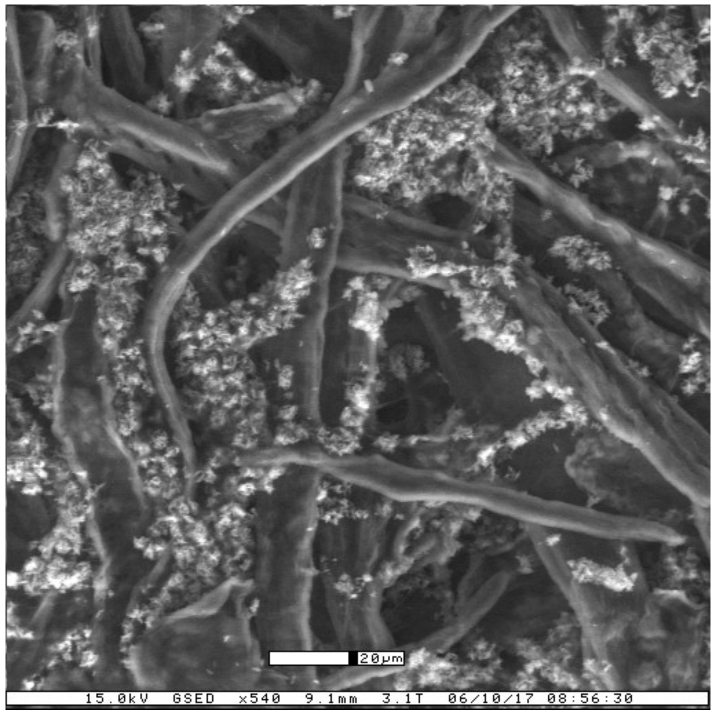


Figure 10. ESEM photo of ordinary white printer paper showing the number of visible additives. They are the small, rounded particles seen along with the fibers.

Retention and drainage aids have increased in recent years. These are chemicals that are added to the fiber and filler suspension to assist the filtration process and minimize loss of cellulose during production while aiding in the removal of excess water. They are water soluble polymers that can be cationic, neutral or anionic and function as flocculants (Roberts 1996). Retention aids come in three types; inorganics, like aluminium sulfate and polyaluminium chloride, natural polymers like cationic starch, or synthetic polymers like polyethylenimine or polyacrylamides. Retention works by inducing flocculation primarily by two types of mechanisms, charge neutralization and polymer bridging (Roberts 1996).

Dry strength additives increase the strength of the paper chemically. They are usually water soluble, hydrophilic, natural or synthetic polymers. Starch, vegetable gum, and polyacrylamides are most often used and also function as drainage and retention aids. Dry strength is an inherent property of paper due to both the drying of the fiber network and the fiber-to-fiber bonds. When a page is torn as the result of tensile stress, individual fibers are both torn and left intact. This demonstrates that the fiber-to-fiber bond strength is not as strong or important to the overall strength of the paper as the strength of the individual fibers (Roberts 1996). The main function of the paper strength additives is to increase the strength of the bonds, without changing the strength of the individual fibers (Roberts 1996).

Starch is the most commonly used of the dry strength additives. It is made cationic, and as a result interacts with the acidic groups of the cellulose. Starch is added to a blend of furnish components and is absorbed by not only the fiber, but also by the fillers and fines, and may help in their retention as well. Vegetable gums are used less frequently than starches. They are very hydrophilic and form viscous solutions, and are probably absorbed through van der Waals forces and hydrogen bonding to fiber surfaces. Fines attract a large portion of the gum, due to the large surface area of the fines. Polyacrylamides are readily absorbed by anionic fibers and furnish components, and can assist draining by serving as a retention aid. They have been shown to increase the strength of paper up to 34% (Roberts 1996).

The use of sizing can refer to both the control of water penetration in a sheet of paper (internal sizing) and the control of penetration through the surface of the sheet (surface sizing) as surface-only modification at the dry-end (Roberts 1996). Internal sizing modifies the water absorbing properties of the component fibers. Usually, sizing material is either neutral or slightly alkaline. Its role is to retard the rate of penetration of a fluid through capillaries both within and between fibers (Sugarman and Vitale 1992). Sizing agents include rosin and alum (Emerton 1980a), but those are beginning to fall out of use because there is increased usage of alkaline products, like calcium carbonate (Roberts 1996). Alum is acidic, and even though it provides an excellcent writing surface, it causes more problems than it fixes (Bierman 1993). The trend has moved towards sizing agents that are effective at a higher pH, like alkenyl succinic anhydrides and alkyl ketene dimmers. External sizing can include water-soluble polymers like starch or polyvinyl alcohol (PVAl) or other soluble cellulose derivatives. These can be applied by an on-machine press at the time of finishing. Other external coatings or surfactants can include kaolin clay, calcium carbonate, either ground or precipitatied, gypsum, amprhous silica and titanium dioxide. Binders include starches, soy protein, and laxens (Roberts 1996). These provide a finer surface of the paper, and are added at the end of production.

After all of the additives are taken into account, the last formation variable to account for the structure of paper is in the dry-end formation of pressing and drying. Paper has a layered fibrous network structure. Its mechanical, optical, and other properties are highly dependent upon the nature of this network between the fibers. When distribution, the bonds between the fibers, and the individual fiber strength. the wet paper fibers are initially laid on the drainage wire, surface tension forces bring the fibers together (Dodson and Herdman 1980). At this point, the weight is about 100 parts water to 1 part fiber ratio (Rance 1980). Under ideal conditions, fibers are randomly distributed in the x-y plane (the plane of the sheet) and are broadly parallel to each other in the z- direction (Radvan 1980). This can be true in non-mechanized paper production, where the fibers are distributed more slowly. Yet, due to the nature of mechanized paper production, there is a preferential orientation of the fibers in the direction of the machine (x-axis) as opposed to cross-machine (y-axis) (Radvan 1980). This orientation can vary with machine speed, as Antoinette Dwan, in her article, "Paper Complexity and the Interpretation of Conservation Research," states, "For example, changing the machine speed alters the fiber orientation, resulting in different strength properties especially in the machine-direction and the cross-direction of the sheet… Although the chemistry of several papers could be the same, the physical properties could be quite different resulting in very different papers" (Dwan 1987:2). The fibers are still broadly parallel to each other in the z-direction (Roberts 1996).

As the paper web enters the wet presses, and the majority of the free water has been removed, and the paper's weight is about 4 parts water to 1 part fiber (Rance 1980). As the paper is pressed or rolled, additional free water and other unbonded water is removed, further consolidating the paper (Rance 1980). In the early stages of drying, it has a 1.5:1 ratio, and the water in the cellulose begins to evaporate (Rance 1980). At this point single molecules of water in the amorphous regions hold the cellulose strands together, which during adsorption, become the hydrogen bonds between cellulose chains (Rance 1980; van der Reyden 1992).

At the point of contact between the individual cellulosic fibers, a strong bond is formed by hydrogen bonds between the polysaccharides at the fiber surface once it is dried. During drying, a sheet can undergo local shrinkage of as much as 20% (Dodson and Herdman 1980; Roberts 1996). Cellulostic fibers are remarkable as they form a strong bond when dried in contact with each other (Emerton 1980b). These bonds are thought to due to multiple hydrogen bonds within the bonded area between the fibers. Research has discovered that 0.4-2% of all hydroxyl groups are bonded within paper (Dodson and Herdman 1980; Roberts 1996). Because the hydrogen bond lengths are so short (a few nanometers), the surface of the fibers must come in very close contact (Dodson and Herdman 1980). While it was originally thought that paper derived its strength from the overlapping of the fibers, paper derives its strength from both the inter-fiber bonds and the inherent strength of the individual fibers (Emerton 1980b and 1980a; Dodson and Herdman 1980; Dwan 1987; Page 1994; Roberts 1996).

Recently, recycled paper has become industrially produced, and it would be remiss not to recognize the impact that its fibers have on the creation of new paper. Many papers have a component of recycled paper fibers, and some are even completely composed of recycled materials. The quality of paper made from recycled fibers is generally lower than that made of unrecycled materials (Roberts 1996). Whether the paper was mechanically or chemically pulped makes a difference in its quality when recycled. Chemically pulped paper, when recycled, has a major reduction in tensile, bursting and folding strength, and stretch. There is an increase in tearing resistance and stiffness. Recycled fibers from chemical pulping have irreversible pore closures in their cell wall which leads to less absorption of water. As a result, the fibers have significantly less flexibility and the bond strength may be weakened. Mechanically pulped paper that is recycled does not show a significant loss of strength (Roberts 1996), yet, these are weaker fibers than those that are chemically pulped.

In conclusion, paper is a composite material with wide variability. Chemically, two papers could be composed of identical materials and fillers, but the formation process creates two very different papers. The fundamental similarity in all paper, regardless of the origin of its fibers, is that it is primarily composed of cellulose. Cellulose fibers give paper its strength through both the inter-fiber bonds and the inherent strength of the individual fibers. Even though there are many additives and fillers that should not be overlooked when assessing paper and its condition, it is cellulose that defines paper. When the cellulostic structure begins to break down, the paper itself breaks down. This can be a result of the internal chemistry of the paper or the result of an external force. The breakdown of the cellulose leads to the deterioration of the paper, and this is what must be addressed in its conservation.

CHAPTER IV

PAPER CONSERVATION TREATMENTS

In order to better understand the goals of conserving paper, it is important to understand the forces that can severely damage paper and the types of treatments previously used to conserve it. Paper can become damaged in an infinite number of ways, but the focal point within this work is severely damaged paper that has become waterlogged, is infected with mold, and has a high level of internal acidity. Additional forces can cause damage to the already compromised papers, and some of those variables are addressed here as well.

This chapter introduces the treatments used in the past to conserve damaged paper, as noted in the literature and practice. These methods are variable and have caused debates within the conservation world as to both their validity and effectiveness. Testing the methods is very difficult, because some may work in the short term, only to be found later to be damaging themselves. In her article, "Recent Scientific Research into Paper Conservation," van der Reyden states, "Treatments cause changes to more than one property. Some property changes may be perceived as beneficial while other may be considered detrimental, and indeed these initial assessments may be reversed over time as the object ages" (van der Reyden 1992: 123). Additionally, testing a composite artifact, like paper, which is variable in its composition and matrix, poses unique issues. Problems with testing conserved paper are discussed at the end of the chapter.

This chapter begins by outlining the mechanisms of chemical degradation of cellulose. Then, each of the three types of paper damage will be discussed, focusing on the causes of the damage, followed by an explanation of the effect to the paper. Each section will conclude with a review of the techniques and methods used by conservators to address these problems. Other important considerations, such as archiving and excavation, will also be covered when it is appropriate.

Causes of Degradation

Three chemical reactions are the main causes of degradation of the cellulose of paper: hydrolysis, oxidation, and cross-linking. These reactions are illustrated in Figure 11. As a result of these actions, the molecular structure of the cellulose chains is altered. This results in a compromised paper. Each of these complex reactions is discussed below.

The hydrolysis of cellulose causes the cleavage of a glycosidic bond as a water molecule (it does not have to be liquid water, but the water vapor in the air is enough to begin this reaction) is added to release glucose monomers and short chains of glucose molecules or glucose oligomers (Wyman et al. 2005). This is called chain scission, the result of which can be seen in Figure 11. The oligomers can further hydrolyze to glucose monomers or they can bond to other cellulose chains. The amorphous regions in the cellulose structure and the glucose oligomers can break down very rapidly to form glucose monomers or bond to other cellulose chains, while the more ordered and rigid

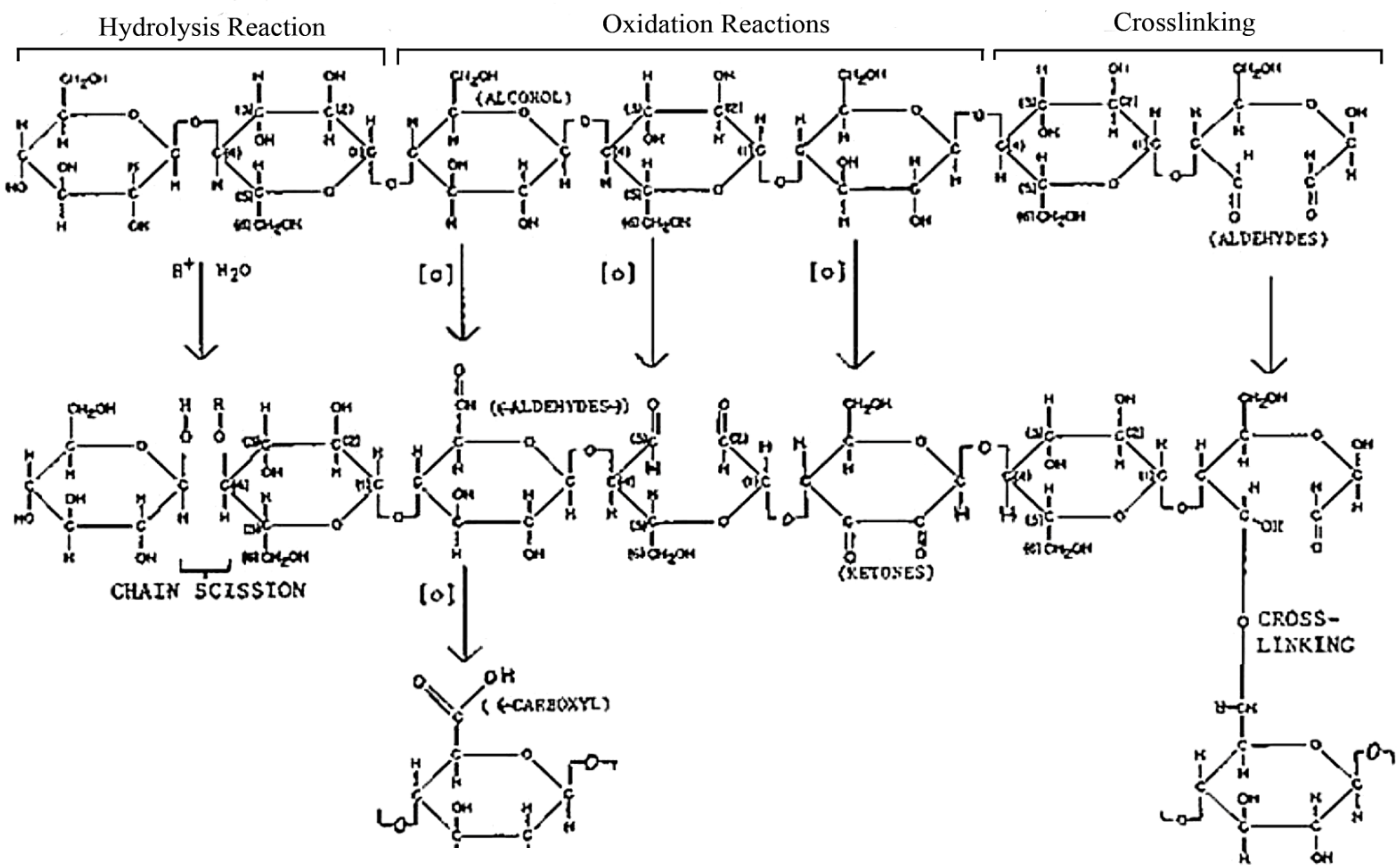


Figure 11. Examples of cellulose reactions. After van der Reyden (1992).

crystalline regions of cellulose react much more slowly. This causes a general weakening of the cellulose structures, since the chains are disrupted. This can also lead to the production of very reactive functional groups, such as carboxyl and carbonyl groups (van der Reyden 1992).

A decrease of the degree of polymerization (DP) by chain scission leads to an increase in crystallinity in semi-crystalline polymers as a general phenomenon (Grassie and Scott 1988). Hydrolysis causes a decrease in the DP by placing constraints on the cellulose molecules to undergo segmental and rotational movement, and therefore, the cellulose molecules move into a more ordered arrangement increasing crystallinity (Sandy, Manning, and Bollet 2010). As a result of the increase in crystallinity within the cellulose structure, the paper becomes brittle and other attributes deteriorate (Sandy, Manning, and Bollet 2010). There is chemical evidence that paper favors hydrolytic mechanisms of cellulose depolymerization over other mechanisms (Baty and Barrett 2007; Baty et al. 2010). There is a direct correlation between the amount of humidity and the rate of strength loss or reduction in DP (Baty et al. 2010).

Oxidation causes changes in the molecular structure as well, and the results of these reactions can be seen in Figure 11. Oxidation of primary hydroxyl groups results in aldehyde groups, carboxyl groups and keto groups in differing degrees (van der Reyden 1992; Margutti et al. 2001). These, in turn, can continue to oxidize, breaking the C-C bond and opening up the pyranose ring, which can lead to cross-linking (van der Reyden 1992; Margutti et al. 2001). Oxidation and hydrolysis work in tandem as water molecules provide both H+ and OH- ions, facilitating both reactions (Baty et al. 2010).

Oxidative reactions can increase the amount of acid present in the paper, as it is catalyzed by a high concentration of hydrogen ions that induce depolymerization, the rate of which is not constant, but increases over time (Baty et al. 2010). In highly alkaline conditions, carboxyl groups are preferentially formed as a result of oxidation, while in lower alkali to acidic conditions, carbonyl groups occur more often. Oxidative reactions are responsible for the yellowing of paper and a loss of strength (Margutti et al. 2001).

Crosslinking reactions occur as a product of both oxidation and hydrolysis. These reactions cause bonding between the individual chains of cellulose, increasing the DP. This reaction does not undo the damage done during hydrolysis and oxidation. By changing the shape and size of the cellulose chains, it is causing the rates of oxidation and hydrolysis to increase.

The causes of paper degradation described above provide a general outline of what happens as cellulose degrades. As discussed before, paper is not only composed of cellulose fibers. In addition to the natural contaminates from the fiber sources, there are many fillers and additives present that affect the degradation of cellulose as well. Paper is incredibly complex and can degrade from a number of factors, but it is especially susceptible to degradation from waterlogging, mold, and internal acidity.

Testing Paper and Conservation Techniques

Before discussing the issues of waterlogging, mold, and internal acidity of paper, it is necessary to discuss the tests used to evaluate paper characteristics, and to recognize the difficulty in testing methods of conservation. In the papermaking industry, tests have been established that follow the standards provided by TAPPI (Technical Association of the Pulp and Paper Industry) or ASTM (American Standards and Testing Methods). These provide guidelines for consistency and accountability within the paper industry, but were not developed for research (Dwan 1987).

The most common tests determine tensile strength, burst strength, and tear strength along with folding endurance (Browning 1977, Casey 1980). None of these is a fundamental measurement, but a combination of such factors as flexibility, bonding strength, and fiber strength, which in turn, are dependent on the type of fibers, their length and thickness, their imperfections, their flexibility, and the pattern of the network, the number and strength of the bonds, the weight of the paper, the apparent density, the moisture content, and many other factors (Casey 1980, van der Reyden 1992).

Tensile strength is measured as the breaking load that a strip of paper can withstand. The average test is completed with a strip that will break at it weakest point. The problem with this test is often the paper will fail at the clamps holding it. Other problems include the fact that the paper is always stronger in the machine direction, and that relative humidity is also a factor. The amount and quality of the fiber bonding is the most important factor affecting tensile strength. Tensile strength decreases if the fiber is excessively beaten (Casey 1980).

Bursting strength is a consolidation of tensile strength and stretch. Paper will burst in a line that is at right angles to the machine direction, as a result of the lower stretch in this direction. This tests the weakest part of the paper affected by formation. Humidity affects this negatively, among other factors (Casey 1980).

Internal tear resistance measures the amount of work it takes to tear the paper. A sample is clamped and then a small cut is made in the strip. The amount of energy that it takes to continue the tear is recorded. Tearing resistance is higher against the grain, and is dependent on the total number of fibers participating in the sheet rupture, the fiber length, and the number and strength of the fiber to fiber bonds. Two factors occur in this test; pulling fibers out of the paper and rupturing the fibers. A slight change in the beating of the fibers can make a great difference in the tear strength. Humidity can make changes in this test, as well as other factors (Casey 1980).

Folding endurance measures the amount of folding the paper will endure before its tensile strength falls below a standardized value for the paper. The paper is folded to a 270° angle at 175 double folds per minute (MIT Fold Endurance tester). Folding endurance is often higher in the machine direction and decreases as the paper becomes thicker. The fibers do not break in this test, but there is a gradual loosening in the fiber bonds, reducing the tensile strength. As predicted, humidity and other variables can affect the results of this test (Casey 1980).

Casey suggests that the folding test could be useful for the measuring of the deterioration of paper by aging, as it is a sensitive indicator for changes in paper that show up before there is a change in burst, tensile, or tearing (Casey 1980). Yet, he states that the results can vary widely, and as a result, some people consider the folding endurance test useless. Folding endurance can vary from one or two double folds to

5000 double folds. He states that an average of at least 5 to 10 measurements should be used and the difference between two samples of 10 to 20 percent, "is seldom significant" (Casey 1980: 1807). The precision of the test can be enhanced by the use of many repetitive tests to lower the statistical possibilities, with the recommendation of 6000 tests per sample. This test may be able to measure that the paper has aged, when compared with a new, similar batch of paper from the same mill, but there are too many factors to consider that it can measure differences in aging among different papers.

The problem with all of these tests when applied to conservation, is that they are designed for industry, and do not account for the variables that affect paper when it ages or becomes damaged. Industrial testing focuses on one particular trait to determine quantifiable data and uniformity within a production group. Dwan states, "The composite nature of paper limits the usefulness of testing isolated components, either chemical or physical. It is difficult to relate a single component back to the overall structure," (Dwan, 1987:1). Attempting to test, measure, or predict paper properties based on individual components are not as successful as testing the physical properties of paper as a composite structure (Dwan 1987). Yet, because of the huge variability in paper, the results of various tests on the characteristics of a sheet of conserved paper can be interpreted in many ways (Dwan 1987; van der Reyden 1992).

When these tests are performed in the papermaking industry, the paper producer can control the number of variables, and have many possible samples from newly produced individual batches of paper. When testing paper from a conservation standpoint, many factors must be accounted for in the interpretation of these tests. To begin with, properties of the paper are affected individually and collectively by such factors as storage, environmental exposure, use, handling, and other factors (van der Reyden 1992). Next, the effect of the damage to the paper must be evaluated. Then, effects of the conservation treatment must be analyzed. Finally, when all of these variables have been accounted for, the evaluation of a test can be assessed, provided one takes into account other factors, such as differing research designs, the test conditions and procedures, and the interpretation of the results by the tester (van der Reyden 1992).

Fundamentally, it is impossible to account for all of the variables within the individualized world of paper conservation. This does not mean that the tests do not provide valid, quantitative data. It means that they should be interpreted within the constructs of the great number of possible variables that could affect the paper. Other qualities, like texture, are not quantifiable and can only be judged against other similar papers by sight and feel. It is up to the individual, well-informed conservator to choose the technique that will best fit the artifact, not just because of a test.

Waterlogged Paper

Waterlogged paper is defined as any paper that is or was totally saturated with water. It can be found in a number of different situations. Waterlogged paper is categorized here in three broad types; submerged, inhumed, and disaster. Submerged paper is paper excavated from an underwater environment, such as a shipwreck. Inhumed paper refers to paper that comes out of a submerged terrestrial site, such as artifacts found in bogs and other submerged sites on land. Disaster paper is defined as paper that has become waterlogged as a result of a disaster or other accident, such as from a flood or the residual water from putting out a fire. It can also be found in other culturally relevant sites, such as at memorials or other celebrations of ritual that have been exposed to the elements of weather. While these three types of paper come from different environments, their mechanisms of deterioration are similar, as is their conservation. The primary goal of conserving waterlogged paper is to attempt to retain as much of the original paper and its properties as possible. This includes its strength, flexibility, appearance, texture, size, and thickness. The paper will never return to its original integrity, but if it is conserved carefully, it should be stabilized enough to be handled and archived.

Conserving waterlogged paper presents many different variables for the conservator to evaluate. Accessing the waterlogged paper can pose problems, especially when it is found in a submerged or inhumed environment. When dealing with unstable artifacts from any wet or waterlogged environment, the artifact must remain wet, or there will be severe shrinking and distortion if it is allowed to dry untreated and unmonitored. If the excavated paper is going to be stored in a water bath for an extended length of time, it is important to have an antimicrobial agent present in the water to inhibit growth of biodeteriorants.

When paper is recovered from an underwater environment, additional factors, such as chloride deposits, must be taken into consideration, and will be discussed below. The conservation of paper addressed here is the literal conservation of paper as an artifact. The ink or other mediums that may have been present on the paper are not addressed here, because the focus is the preservation of the paper, not the preservation of the media on the paper. It is not that the media is not important, and should be tested before undergoing any treatment in hopes of preserving it as well.

When a paper artifact is recovered from an inhumed environment, it must be kept wet as well. With repeated baths, any foreign contaminates should be washed out, but care should be taken to prevent the washing out of structural components. A biodeteriant should be included in the baths as well to prevent mold growth if the conservation is conducted over a long interval of time.

Disaster paper adds a different sort of urgency to its removal from the disaster area. In a flood or fire situation, there is often a very large quantity of waterlogged paper, especially in libraries, schools, and offices. The paper must be triaged as soon as possible to prevent it from drying without treatment or growing mold. An additional problem for the excavators/conservators is that the building or archive may not be stable enough to access. This situation becomes a race against time, as the sooner a wet artifact enters treatment, the fewer the additional problems.

A sub-category of disaster papers are the papers that have undergone repeated episodes of wetting and drying, such as paper artifacts that have weathered outside. They have been waterlogged and air dried, sometimes repeatedly, and exposed to sun and wind. Other potentially damaging accumulants, such as in the case of paper artifacts from a memorial, can include candle wax, bird and bug droppings, and other rotting organic material. Sometimes the zeal of the excavator/conservator can cause additional problems in any of these three types of waterlogged paper, and those issues must be addressed in the conservation as well.

Waterlogging causes degradation of paper by affecting the bonds within the cellulose structure of the paper. Cellulose is long chain, linear polymer that is formed by a crystalline microfibrillar linear polysaccharide of β-1,4-linked polysaccharide of β-D-glucopyranose (Roberts 1996). Cellulose is never found in a completely crystalline form, but is partly crystalline and partly amorphous material; the percentage of crystallinity varies between 50-90% depending on the source material and the method of measurement. (Emerton 1980a; Dwan 1987; van der Reyden 1992; Roberts 1996). In order to make paper, prepared cellulose fibers are suspended in an aqueous solution. This causes the fibers to become saturated with water in the amorphous areas, and causes the fibers to be held together as a result of surface tension. When the water is removed from the matrix, as a result of gravity, heat, or compression, it causes the fibers to become intertwined and bonded (Cardamone 2001; Cardamone and Baker 2001). Paper derives its strength from both the individual fiber strength and from the strength of the bonds between the fibers (Page 1994).

After a paper sheet has been dried, the bonds can be totally disrupted when high humidity or liquid water is reintroduced (Emerton 1980b). When paper becomes waterlogged, even though it originated in water, it becomes severely damaged. When saturated with water, conventional papers only retain 3-8% of their original dry strength (Vitale 1992a; Robert 1996). Chemicals, like sizing, can be applied that add to the “wet strength” of the paper, but it still loses much of its strength when saturated. Roberts states, "Since the swelling of cellulose is not completely reversible, mechanical recovery is incomplete…" (Roberts 1996: 76). Wilmer A. Wink, in his *TAPPI* (Technical Association of the Pulp and Paper Industry) article, "The Effects of Relative Humidity and Temperature on Paper Properties," stated,

> Irreversible effects, resulting from an excursion of paper to a high relative humidity, are often observed. These can be an appreciable order of magnitude, with the properties, in certain cases, *altered to such an extent that they no longer characterize the original material.* This effect evidently originates with the swelling and shrinking of the fibers and with the relaxation of dried-in or built-in stresses; the major effect occurs on the *first* exposure of paper to a high relative humidity, exceeding approximately 65%; *it is dependent upon the extent of the excursion and it permanently alters such surface properties as gloss and smoothness, as well as dimensional and strength properties. These changes are nonrecoverable* by manipulation of the moisture content or by preconditioning and conditioning the paper (Wink 1961; 176).

Suffice to say, it is not recommended to expose paper to water, since it will not retain the original qualities of the paper prior to exposure. Generally speaking, manuscripts and books dated earlier than 1840 will absorb 80 percent of their original weight in water. Some may absorb as much as 200% of their original weight. Since there is a greater concentration of proteinaceous material and receptivity to water in early books and papers, they are especially vulnerable to mold when damp. Modern books, other than those with the most brittle paper, will absorb an average of up to 60 percent of their original weight (Waters 1993).

Water affects paper in two distinct ways: it is absorbed into the pores of the paper and it swells and plasticizes the fibers (Vitale 1992a). Many of the hydrogen bonds between the cellulose fibers are broken as a result of the water molecules, causing a severe loss of strength upon wetting (Dodson and Herdman 1980). By breaking these bonds, the water acts as the mechanism for hydrolysis. It is suggested that the only important reaction for strength loss is hydrolysis, based upon the idea that the higher the moisture level, the more rapid the deterioration (Page 1994), but other mechanisms of deterioration are at work as well. Since the individual fibers absorb water, they become dislodged and loose from the original matrix, causing a loss of strength as they are no longer interwoven tightly and compressed against one another, plasticizing the aggregate sheet (Sugarman and Vitale 1992). The surface texture of the sheet is lost, and changes in the fiber shape also occur (Vitale 1992a). Additionally, water and high humidity can increase the degree of crystallinity in the cellulose chains (Sandy, Manning, and Bollet 2010). With an increase in crystallinity, there is a decrease in tensile energy absorption and strength.

While hydrolysis appears to be the dominant cause of waterlogged paper deterioration, the mechanism of oxidation is also in effect (Grattan 1978; Whitmore 1994). Oxidation breaks glucose chains, which can be accelerated by additional oxidizing agents, such as the chlorides found in salt water. It works by abstracting a hydrogen ion from one of the carbon atoms within the chain. This accelerates the decomposition as it opens sites up for further breaks (Whitmore 1994). Waterlogging with salt water provides additional problems, although immersion in standard paper conservation washing aids (salt solutions like CaOH and Na(OH)2) does not seem to affect the mechanical processes (Vitale 1992a). The chlorides are present in seawater and undistilled fresh water can cause oxidation after treatment if not removed. Before treatment, paper from a seawater environment should be rinsed repeatedly, to remove the chlorides. One advantage of saltwater, is that it provides an alkaline environment that will prevent an increase in internal acidity (Cronyn 1992).

Eliminating reactions are also present in waterlogged paper. These peeling reactions attack the ends of the cellulose chains at the carbonyl groups. While these may not be a major player in the degradation of waterlogged paper, they may increase the risk of oxidation, by breaking carbonyl groups that are attached in the middle of the chain. All three of these mechanisms are causes for paper deterioration of both dry and waterlogged paper, and if anything may work much faster within the watery environment.

Within shipwrecks there are often both copper and iron contaminates present in the environment. Shipwreck artifacts are often referred to a “closed cell” artifacts, as often the individual artifacts become encrusted, and are essentially sealed off from the ocean environment. This is both good and bad: it is good for paper because it protects it from the mechanics of moving water, while maintaining moisture in a cold and dark environment. It is also bad for the paper, as that means that whatever else is in the closed cell, like some iron nails or some copper coins, will have an opportunity to react with the paper as they corrode. Iron and copper ions can lead stain objects, as well as altering the chemical composition of the paper (Jakes and Mitchell 1992).

Not only waterlogging can negatively affect paper, but just a high level of humidity can cause damage to paper. The difference is that humidification does not result in total saturation of water into the paper pores, which would result in the breakage of fiber to fiber bonding, and cause a more severe loss of strength. It does disrupt the paper by the relaxing the fibers' saturation point or plasticized state that releases the stresses that were dried into the fibers when the sheet completed (Sugarman and Vitale 1992).

At this time, treatments suggested for waterlogged paper provide few options. The goal of the treatment of waterlogged paper is to return the paper to as close to its original texture as possible. The recommended first step in conserving paper that has been in a disaster context is to get it into a freezer as soon as possible (Turchan 1988; Zhiqing and Daying 2007; Silverman et al. 2007). The reasoning for this is that mold will begin growing on wet paper very quickly. If one has a large volume of wet material, putting it into a freezer buys one the time to address each artifact individually. Within the literature and practice, there are several suggested methods for treating waterlogged paper, including air drying, freeze drying, vacuum freeze drying, thermal drying, and vacuum packing (Silverman et al.l 2007).

Air drying is just what it sounds like: allowing the item to dry in the air. The most basic form is referred to as free drying, since the paper is allowed to dry unrestrained or controlled (Sugarman and Vitale 1992). This method is results in a cockling (severe uneven warping of the sheet). This is a result of the hydrogen bonding fixing fibers to one another as they are shrinking, and so causing distortion, especially in the z-axis. Other air drying methods are often accompanied by fans or by pressing the artifact between paper blotters with additional weight applied (Silverman et al. 2007; Kaplan and Ludwig 2011). The blotters remove the excess water from the wet artifact by capillary action, and are changed often to encourage drying. The weights discourage cockling as it dries. Interleaving wet books is also an air-drying technique. Individual sheets of dry paper are placed between wet pages and pressed, which causes a wicking of the water to the dry sheets, continuing until the wet pages are mostly dried (Pinhong 2006). The problem with this method and its use on wet books is it can have additional negative effects on the binding, already compromised from the wet conditions.

There are variations on air drying. One recommended type of air drying is called the "Early Restraint Method," which has two different variants, Type One and Type Two (Sugarman and Vitale 1992). Both involved the paper being removed from a water bath to a blotter on a nylon mesh support. When the surface of the paper regained its original appearance, the samples were placed between fresh blotters. In Type One, the blotter was covered with a foam rubber pad. After about 2 minutes the blotters were changed, and the samples (between blotters) were placed between ¼ inch thick felts and under plate glass. The blotters were changed the next day, after 1 week, and after 3 weeks. This is the common type of drying employed by many conservation labs. Type Two follows the same procedure, only with the addition of lens tissue placed in contact with both sides of the paper in the "sandwich." This variation on Type One was selected to observe the subtle differences in the texture of the paper. And as it turned out, Type Two had the best overall appearance due to the inclusion of the lens tissue, when compared to the original control and Type One (Sugarman and Vitale 1992).

Another type of air-drying has been suggested, called friction drying. It is done to impart stretch to a sheet during drying. The paper is placed onto a board or similar structure to provide strength, and a friction paper is then placed on top. The sandwich is then beaten in the traditional Japanese method of overlapping and crosswise brushing. This causes the paper to A) lose its water to the friction paper, with excess draining off, and B) it may help re-bonding based upon the same types of pressure used in Japanese paper production. During industrial papermaking, increasing the pressure during the wet-pressing stage showed an increase in the tensile strength of the finished paper, believed to be caused by an increase in bonding (Vitale 1992b). Experiments with friction drying have been shown to have little effect on the mechanical properties, with only a small of amount of strength and shape lost compared to controls. When combined with wet pressing (putting significant amounts of pressure, like from a book press, onto the paper to remove the initial excess water), this process was found to be even more accurate to the original appearance of the paper (Vitale 1992b).

A complementary air drying technique that can be used on paper that was wet, then allowed to free dry, is the air-dried-humidification method (Sugarman and Vitale 1992). Since the paper was allowed to free dry, it is cockled and weak. The free dried paper is placed into a humidity chamber. The fibers within the paper will swell slightly and relax from the humidity. Then, the paper is removed from the chamber and is dried using a restraint method. This paper will acquire the characteristics of paper dried using the restraint method, not displaying its earlier appearance of cockling (Sugarman and Vitale 1992). Humidification chambers are often employed if a paper becomes severely wrinkled or distorted.

There are several positive points of the air drying methods. The first positive is that if the paper is dried quickly, there is no danger of a mold infestation. By applying restraint or friction drying treatments to waterlogged paper, the sheet is compressed and constantly flattened, so it retains most of its original characteristics. There is little to no cockling, and if the paper was already bent or folded prior to its waterlogging, it can appear to be in better shape than before it was waterlogged.

The problem with this treatment is that it does nothing to restore any strength to the paper. It is almost impossible to treat a bound book using this method without removing the binding. Also, because of the labor-intensive nature and the limits of space, it can be very expensive and incredibly difficult to treat a large quantity of paper at once. Yet, it is the best conventional drying method since the paper retains the most of its original properties compared to the other techniques.

The most commonly advised treatment methods for waterlogged paper are freeze drying or vacuum freeze drying, especially for large quantities of paper. (Turchan 1988; National Archives and Records Administration 1993; Capolong and Barresi 2004, Kaplan and Ludwig 2011). Freeze drying should be undertaken if the item is mostly stable and cannot be air-dried in a 24-48 hour time period. While air-drying may be easier, the paper becomes exposed to other possible degradation elements, such as mold. Mold will begin growing within 36 hours in a humid environment (Swartzburg 1983a and 1983b), at a relative humidity of 68% (Buchberg 1983). A cold environment may slow mold growth, and a frozen environment retards mold growth, but the mold is still present. Paper is at risk for mold from either drying too slowly or from maintaining a high relative humidity, both of which may be the case in a thick stack of papers or a book.

Freeze drying is a process where the wet material is frozen and the water within the material is sublimated. The temperature in the industrial freezer must be maintained no warmer than -10 degrees Fahrenheit (Kaplan and Ludwig 2011). The main problem with this procedure is that the water has already disrupted the matrix of the paper by swelling the individual fibers. Waterlogged paper has free water within the matrix of the paper, as well as absorbed water within the fibers. The free water will readily form ice crystals separate from the fibers as soon as the temperature drops below freezing. At this point, the paper is beginning to dry, even though the RH in the freezer is 100%. As the temperature is further reduced, more water will come out of the fibers and condense onto the ice crystals that fill the spaces between the fibers. This ice will grow and expand, pushing the drying fibers further apart. Additional problems can arise when freezing books. When the Virginia Historical Society flooded in 1993, their conservators considered freezer-drying, but decided that it was undesirable. They believed that too much damage was inflicted when ice crystals are formed in the cellulose, and that since the binding on books dries first, additional deformation was caused by freezing (Rusch and Herro 2000).

The argument given in support of freeze-drying is that it does not cause further damage to water soaked material (Capolongo and Barresi 2004; Silverman et al. 2007), which is true when one considers the paper to have already lost 93% of its original tensile strength when it became wet. Freeze-dried paper had a 63% decrease in strength, compared to the control, untreated paper (Vitale 1992a). The frozen water holds the cellulose surfaces apart, preventing a complete reformation of interfiber bonds during drying (Vitale 1992a). Additionally, cold fibers are stiffer than room temperature fibers. This prevents full-scale bonding as the fibers cannot conform to one another during the freeze drying process, so freeze dried papers were found to have fewer bonds than air dried papers (Vitale 1992a). Usually, paper has a moisture content of 8%, and freeze dried paper should not be handled until it reaches 5% (Turchan 1988).

Vacuum freeze drying is a similar process. The use of a vacuum within the freeze-dryer will allow water crystals to sublimate more quickly (Smith and Grider, 2001). Under the pressure of a vacuum, the artifact is colder, and smaller crystals of ice are formed, causing less damage to the matrix of the paper. Vacuum freeze drying is a highly recommended choice for conserving large quantities of waterlogged paper (Kaplan and Ludwig 2011).

There are problems with this technique. Particularly heavy damage is caused by defreezing from ice treatment under vacuum. The slow passage of water from the solid phase to vapor phase negatively influences the reticular structure of the paper, causing a decline in mechanical resistance (Adamo et al. 1998). Another downside to this technique is the expense of the equipment or the expense of using an outside firm specializing in this method of conservation. The equipment is incredibly expensive, and there are number of people who have reported problems with using outside service providers. These problems have included the mislabeling of materials, poor storage and packing of materials, and in one case, the truck bringing dried paper back to the Chicago

Historical Society was not waterproof, and returned the materials wet all over again (Turchan 1988; Rusch and Herro 2000; Kapland and Ludwig 2011).

Vacuum freeze drying is especially suggested in the case of waterlogged books. Some have suggested that wicking paper sheeting be placed between the individual leaves of a book to decrease drying time, and to keep the pages separate. The only problem with this technique, is that is requires the waterlogged sheets to be handled and possibly damaged during their most fragile time. Smith and Grider suggest sheeting sprayed with a fungicide placed between each page, prior to freeze-drying (Smith and Grider 2001). This may not be necessary for paper that has not yet seen mold bloom, but on paper already affected by mold growth it is a good idea.

Vacuum thermal drying is another technique. The wet paper is placed within a vacuum chamber and heated air is allowed to dry it. This method distorts paper and can cause feathering of ink (Kaplan and Ludwig 2011). While this may be cost effective for large quantities of paper, it is one of the worse treatments, as it combines air drying without compression and possible accelerated aging due to the heat.

Thermal vacuum freeze drying is a patented technique that is marketed by one company, Document Reprocessors, as Thermaline™. Their methods are patented, but from the information within their brochure is seems that the wet materials are loaded into a vacuum chamber which, by reducing the pressure along with the use of controlled heat, vaporizes the water/ice. The resulting vapor is removed from the chamber by specially-designed vacuum pumps. The extracted and isolated vapor is then heated and converted to steam and exhausted to the atmosphere. Thus, the only emission is steam

(212°F at sea level). Document Reprocessors claim to be the nation's leading experts when it comes to salvaging and restoring water-damaged books, photographs and materials. The average drying time for books and documents is 8-10 days, depending on the degree of water damage. They have treated tens of thousands of books and millions of individual pages. They charge sixty dollars for a square foot of waterlogged material for the Thermaline™ process, with other charges from the packing, moving and etcetera (Document Reprocessors 2010). They promote the idea that it is cheaper to have them treat your papers than it is to replace them, which may be true, but certainly the integrity of the material is compromised due to the damage caused by their process.

Another method that can be used to dry paper is the use of organic solvents like ethanol or acetone. By introducing the wet paper to baths of organic solvents of increasing purity (start with 25%+ solvent/water solution and increase the solvent ratio), the solvent will effectively drive out any water within the matrix of the paper. It was found that the immersion of paper in ethanol gave a breaking length increase of 10%, and yellowing and acidity diminished as well in already damaged paper (Cheradame, Rousset, and Ipert 2003; Ipert, Cheradame, and Rousset 2005). The result is water-free paper. There are a few problems with this method. Organic solvents are expensive and their disposal is problematic. If there are inks or other media present, they may be negatively affected, but this is a risk in aqueous washing as well.

The methods listed above are reasonable techniques when one has paper that has become waterlogged. When the conservation is completed, these papers can be archived and examined with a careful touch, but they are still weaker than they were originally.

Unfortunately, there are situations where these techniques are not enough to conserve all wet paper. For instance, if a waterlogged composite artifact or item is recovered with a paper component, the conservation can become difficult, and conservators are forced to choose which of the components to preserve. Another problem that is not discussed in the conservation literature is how to conserve paper so damaged that it cannot be removed from its context, like in the case of paper fuses within cannon balls. This paper cannot be air dried, as the sheer force of the cockling from the inherent uneven drying would cause the paper to break into fragments, and freezing it would shatter it completely. The sense is that they would potentially be a loss or one would simply try to reconstruct whatever was left.

None of these conservation treatments can take waterlogged paper back to its original condition, and none of them add any strength to the weakened paper. There is agreement among conservators that strength is lost in all papers that are waterlogged and conserved using the above methods (Dwan 1987; Turchan 1988; van der Reyden 1992; Vitale 1992a; Carlsen 1999). When a conservator is called to duty and informed that one million pounds of paper is waterlogged and has to be dealt with within 48 hours, it limits the choices one can make in the conservation of such a large volume of material. When one is dealing with severely damaged paper that will not stand up to the types of forces that are exerted from the traditional methods, it leaves even fewer choices to the conservator. The treatments listed above have been adequate to conserve some instances of waterlogged paper, leaving it weakened, yet still available to careful researchers.

Mold on Paper

When considering waterlogged or other compromised papers, a discussion of mold must be included. Mold or mildew, which is all too often associated with wet or damp papers, are generic terms that refer to various types of fungi. There are over 100,000 known species of fungi, and possibly 200,000 unknown molds and they are present in nearly every environment (Nyberg 2003). Many are dangerous to people and other living things.

Mold spreads by producing large numbers of spores, which become airborne and settle into new environments to germinate. When they germinate, hair-like structures known as mycelia, the visible part of mold, sprout and produce more spore sacs, starting the cycle over again. Mycelia occur when there is sufficient moisture and nutrients present (Florian 2000). Mold is incredibly versatile, evolved, and clever. Some mold can change into a form with a different species name. It can change into a yeast, and then change back into a mold. Mold's color and other visible features depend on its environment and what it has been eating, so it is very difficult to identify one mold from another without consulting a mycologist. Mold spores can remain viable and dormant for years after being produced. Some molds can be dangerous to people and pose a health hazard. The toxins and volatile organic compounds released by the organism continue to affect other materials and organisms, including humans, even after the mold is dead (McCrady 1999). Additionally, there are no practical environments in which mold does not exist (Patkus 2004). Unless you live in an autoclave, mold is everywhere and must be actively removed.

The spores or conidia are a single cell organisms of low metabolic activity that possess reproductive and survival functions, and are usually spherical structures about 2-10µm. Each conidium has a rigid, protective outer wall that is water impermeable that surrounds the protoplast of the cell. The protoplast contains cytoplasm filled with the organelles needed to run the metabolism of the cell, in addition to genetic material, food, and a water solution of enzymes. The cell wall becomes water permeable when germination is initiated, and the layer between the wall and the protoplast is hygroscopic (Florian 2000). The allergenic or toxic substances attributed to mold are usually produced in the cell wall of the conidium and mycelium. Again, it must be recognized that the allergenic or toxic substances from these parts, is active in both dead and living molds. For example, *Stachybotrys atra* toxin has been shown to be still present and viable after the conidia and mycelia have been killed by autoclaving (Florian 2000). Even if the mold in a paper collection has been killed, it does not mean that the paper has been made safe enough for handling by the general public.

Mold affects paper three ways: it causes damage, it becomes unsightly, and it can spread from one document to another easily. Cellulolytic (of, relating to, or causing the hydrolysis of cellulose) fungi, when growing in favorable environmental conditions, can damage or destroy paper material in a short time (Adamo et al. 2003). Fungi affect the surface qualities of the paper by the production of enzymes aiding in the digestion of the cellulose fibers, and by producing and secreting a variety of pigments. The pigments are present in the spores and mycelium, and are secreted by the fungi into the paper structure (Szczepanowska and Lovett 1992). The most common forms of mold found in paper are the *Altermaria solani, Penicillium notatum, Fusarium oxysporum* and *Chartomium globosum.* (Strzelczyk 1981; Szczepanowska and Lovett 1992).

Molds thrive best in a damp, warm environment. When books or paper are stored in an environment of 70° Fahrenheit or more and have a relative humidity over 70%, it is almost guaranteed that there will be a mold outbreak. Yet, some can still thrive in an environment where the temperature is 50° F and the relative humidity is 45% (Nyberg 2003).

Currently, there is no catch-all method for the removal of these molds, as each responds differently to treatment methods. Molds are incredibly difficult to kill, especially in their dormant, desiccated form. The dormant form of mold is most often found in paper and books, like a ticking time bomb, just waiting for the right conditions to bloom (Gustafson et al. 1990).

If a collection of paper artifacts or books becomes damaged by water or humidity, the first priority is to avoid a mold outbreak. Mold will start growing on wet or damp materials within 36 hours, and can begin to form on a wet book within hours (Patkus 2004). Once mold has bloomed on an item, it will reappear whenever favorable environmental conditions allow. As such, mold can never be eradicated unless it is effectively killed (Sinco 2000). It is currently held by the conservation world that the best method of dealing with a mold outbreak on wet materials is to freeze the materials as soon as possible, dry the materials, and then develop a treatment strategy to deal with the mold (Nyberg 2003). The fundamental goal of any treatment for mold is to kill the entire mold colony present on an artifact. There are several proposed mold extermination techniques used by conservators that include mechanical, environmental, chemical, and nuclear treatments. These methods are reviewed below.

In undertaking mechanical cleaning, the first step is to ensure that the moldy paper is dry (Florian 2000). Paper is much weaker when it is wet, and should never be mechanically cleaned in this state. The removal of mold using mechanical methods should be undertaken with a great deal of care, as this can cause more damage to the integrity of the paper than dormant mold. Additionally, since this technique does not kill mold, but only removes the mold for aesthetic reasons, care should be used when performing this treatment. A popular method for the removal of mold is a vacuum aspirator (McCrady 1999; Nyberg 2003). While these small HEPA (high efficiency particulate air) vacuums are effective in removing some spores and other parts of the mold, they do very little for the discoloration which may have penetrated deep into the matrix of the paper. They can be used alone or in conjunction with such products as smoke sponges or MagicRub® or Statler-Mars® plastic erasers (Reidell and Smith 2001). These should be used very gently, as it is possible to rub the mold further into the paper. Very little should be expected from these methods, as the mold may already be deep within the matrix of the paper. A soft brush can also be used in the removal of mold, but the debris should be vacuumed immediately (Patkus 2004). The unpleasant smell associated with a mold contamination may be treated by exposing the paper or books to baking soda or charcoal, in an enclosed environment (Nyberg 2003; Reidell and Smith 2001).

Another technique suggested by Szczepanowska and Moomaw is the use of a laser for the removal of mold and mold stain. During their experiment, they found that stains from two of the four experimental molds, *Alternaria solani* and *Penicillium notatum*, were completely removed. In the case of the *P.notatum*, the fungal bodies imbedded in the paper matrix were removed along with the stain. The other two mold stains used in their experiment, from the fungi *Chaetomium globosum* and *Fusarium oxysporum* did not seem to be affected, but the *F. oxysporum* stained sample did show evidence that the laser removed the mycelia, leaving voids in the paper matrix where they had previously been present (Szczepanowska and Moomaw 1994). There did not seem to be any additional damage to the paper, even under magnification.

While this treatment is especially interesting for stain removal, is it provocative for the removal of mold itself. Szczepanowska and Moomaw only experimented with one particular type of laser, a neodymium YAG (yellow and green) pulsed laser, yet many different types of lasers with different frequencies and wavelengths exist. Hopefully, someone in the future will pursue this line of investigation into the removal of additional types of fungal stains.

Ultra-violet light can be used to treat mold infestations as well. It does inhibit mold growth and it may kill the mold. It is not recommended as a full scale treatment for books and paper. The amount of exposure needed to kill mold would have an adverse effect on the paper and actually cause fading and accelerated aging (Nyberg 2003). It has been suggested for small, localized outbreaks, but this would require a short exposure time and constant monitoring. It is recommended that this would be conducted outside, in the sunlight, but the humidity must be below a mold inducing amount (Reidell and Smith 2001).

Chemical treatments to inhibit or kill mold fall into two categories: fungistatic or fungicidal. Fungistatic treatments are those that prevent the mold spores from germinating, but do not kill the mold. For instance, freezing the mold sends it into hibernation, but if it is placed back into an environment that is nurturing to the mold, it will grow again. Fungicidal treatments kill the mold and its spores. Currently, there is no safe, large-scale chemical treatment for mold that imparts lasting or residual mold control. That is why it is so important to change the environment in which the material is stored, thereby inhibiting mold growth. Additionally, there is some evidence that books and papers treated with fungicides may be more susceptible to mold after treatment than they were prior to the outbreak. Many also question the damage that the chemicals do to the structure of the paper, and whether the treatment itself will do more damage than dormant mold.

Often the chemicals used in treatments pose health risks for the conservators, and treated paper may remain toxic to those using them in the future. For these reasons, it is recommended by most of the researchers who study the problems of mold on paper that the use of chemicals to treat mold should no longer be used for library, archival, and museum collections (Strzelczyk 1981; Szczepanowska and Lovett 1992; Nyberg 2003; Patkus 2004). In addition, chemical treatments can cause reactions between some of materials within a collection.

Fungicides powerful enough to achieve 99% mortality for fungi, are assumed to be toxic to humans as well. In considering the use of fungicides and fumigants for the prevention or treatment of mold growth, two basic facts should be kept in mind: 1) all biocides are chemically reactive, i.e. they are capable of reacting with and altering materials to which they are applied and 2) all biocides have some level of mammalian toxicity (Haines and Kohler 1986). Neither of these is an endorsement for continued use of these treatments.

There are two methods of application for these chemical fungicides: fumigation and application. Fumigation is much more appealing than application, as it can be done to more artifacts in less time, and applied in a closed environment. Currently, the literature does not conclusively recommend any applied fungicide. The chemicals that were used in the past have been found to be either ineffective, toxic to humans, or both. (Haines and Kohler 1986; Gustafson et al. 1990; Nyberg 2003).

There are six types of fumigants that are suggested in the literature: ethylene oxide, methyl bromide, sulfuryl fluoride, thymol, orthophenyl phenol, and paradichlorobenzene. Some of these provide better levels of success than others and are used more often. And while some of them have fallen out of use, or were found to be ineffective, it is important that they be mentioned. Since they were used at one time, there may be consequences in the future to collections and their caretakers from the paper's exposure.

Ethylene oxide was developed in 1859. By the late 1920's it was in common use as a fumigant for grain, and by the 1950's it was used in museums, libraries and archives. Ballard and Baer (1986) provide an excellent study of the history, use, effectiveness, and its hazards. It kills microorganisms by denaturing their proteins and subsequently modifying their molecular structure. It is considered a disinfectant, fumigant, insecticide, and a sterilant (Environmental Protection Agency 2011). It works to destroy or eliminate all forms of microbial life in the inanimate environment, including all forms of vegetative bacteria, bacterial spores, fungi, fungal spores, and viruses. In 2005, the Occupational Safety and Health Administration (OSHA) released a new standard for exposure to ethylene oxide of 1 ppm. OSHA has determined that exposure to EtO, "presents a carcinogenic, mutagenic, genotoxic, reproductive, neurologic, and sensitization hazard" (Occupational Safety and Health Administration 2005). In 1980, museums and libraries were found to have the lowest record of implementing standards for maintaining and monitoring equipment for the use of ethylene oxide (Ballard and Baer 1986). In his article "The Use of Gamma Rays in Book Conservation," Patrick Sinco (2000) stated that exposure limits of ethylene oxide have been regulated to the extent that EtO, once a mainstay for mold control, is no longer a viable treatment option. He quotes Mark Gilberg, a research coordinator at the National Center for Preservation Technology and Training, as stating, "For me, many years it was ethylene oxide. But the exposure limits got to the point where they were so low that it was almost impossible to carry out,"(Sinco 2000: 39). Sinco also quotes Ellen McCrady, editor of the Abby Newsletter, "Ethylene oxide is the main alternative to radiation, but we know now that it is very hard to get back out of certain materials . . . no matter how many times the air is purged while they are in the chamber. . . . The EtO that remains will eventually escape from the book or document and endanger staff and readers," (Sinco 2000: 39). EtO is rarely used anymore by libraries or museums as a result of the danger to the conservators, and is no longer recommended (Wood Lee 1988; Nyberg 2003). And yet some still use it with the belief that they can off-gas it enough that it is no longer a threat (Basset 2007; Silverman et al. 2007). Many countries ban the use of EtO due to the associated health risks, and in the future it may be banned everywhere as a conservation tool (Adamo et al. 2001). Ethylene oxide is known by a variety of other names, including EO, EtO, ETO, anprolene, dihydrooxirene, 1,2-epoxyethane, oxacyclopropane, oxane, oxidoethane, oxirane, dimethyl oxide, carboxide, oxyfume, and pennagas. It is highly flammable, and is usually used in a 10% concentration with a carrier gas (Wood Lee 1988).

Methyl bromide is most commonly used in the fumigation of insect infestations. It is not particularly effective as a fumigant for mold growth, but is occasionally used as one. It is thought to be 10X less effective than ethylene oxide by dosage (Ballard and Baer 1986). As a gas or liquid, it is easily detected, as it has a chloroform-like smell. It is highly toxic by ingestion, inhalation, or absorption through the skin. The tolerance level established by OSHA is 5 ppm. Methyl bromide affects the central nervous system, respiratory system, skin, and eyes. Acute effects usually occur 30 minutes to 6 hours after exposure and chronic effects are usually limited to the central nervous system and include muscular pains, visual, speech and sensory disturbances and mental confusion (Occupational Safety and Health Administration 2004). Methyl bromide should not be used for the fumigation of any protein based material, as it seriously damages the protein structure. For example, leather bound books should not be exposed to methyl bromide, as they will become black and brittle (Ballard and Baer 1986; Wood

Lee 1988). It also leaves an irreversible foul odor, softens adhesives, and is simply not very effective as a fungicide. Methyl bromide, monobromomethane or bromomethane is also known by the proprietory names Brom-O-Gas, Brozone, MeBr, Meth-O-Gas and Terr-O-Gas (Wood Lee 1988).

Sulfuryl fluoride is most often used for the fumigation of termites in building structures. It has very high penetration, even without a vacuum. Like methyl bromide it is not known to be effective against mold, but is occasionally used for that purpose. It is an odorless, colorless, tasteless gas, and is usually available only to licensed fumigators. The OSHA standard is 5 ppm (Occupational Safety and Health Administration 2004). It may be ingested, inhaled, or absorbed through the skin. It has not been tested extensively, and its carcinogenic and reproductive effects are unknown. Acute effects include nausea, vomiting, and abdominal pain. Chronic effects include defects in bone and teeth, and lung and kidney damage. Sulfuryl fluoride is most often available under the trade name Vikane (Wood Lee 1988).

Thymol is a white crystal with a distinctive aromatic odor and taste, derived from thyme oil and may be mixed with camphor in its crystalline form. Thymol is sometimes used in its gaseous form (produced by heating the crystalline form to release thymol vapor) as a fumigant for small quantities of materials. In order to be safely handled following fumigation, materials must be aerated. This removes any residual protection against mold growth, but renders the materials safe for staff and patrons. Thymol has also been found to cause parchment to become brittle and cause the softening of varnishes and paints. Some authorities have declared thymol to be fungistatic but not fungicidal in their tests (Nyberg 2003). It is moderately toxic by ingestion and inhalation. Studies indicate that exposure to thymol vapors can affect the central nervous system and the circulatory system. No precise level for minimum exposure has been established (Occupational Safety and Health Administration 2004).

Orthophenyl phenol (OOP) is considered slightly less toxic than thymol, and has been suggested to be used in place of it (Haines and Kohler 1986; Gustafson et al. 1990). The Merk Index lists it as a "slightly toxic irritant" when inhaled. It is moderately toxic by ingestion. Relatively little testing has been done regarding the toxicity of OPP, and no exposure level is available. In tests conducted by Haines and Kohler (1986), orthophenyl phenol was found to be an ineffective fumigant. Of the seven fungi tested, fumigation with orthophenyl phenol failed to completely halt mold growth even after 10 days of continuous exposure to the vapors under controlled conditions (Haines and Kohler 1986; Gustafson et al. 1990). Some experts feel that orthophenyl phenol is not fungicidal as a vapor (Nyberg 2003).

Paradichlorobenzene is used as a mild fumigant. It is not a proven fungicide, but seems effective as a fungistat. Three weeks of exposure is needed for the application to be effective. Paradichlorobenzene seems to be most useful as a treatment for preventing mold growth, especially in small, enclosed spaces (Nyberg 2003). It is hazardous if it is inhaled, ingested, or in contact with skin.

Other chemicals have been experimented with as fungicides, but those mentioned above are most often referred to in the literature. In addition to serving as fungicides, chemicals have also been used in the cleaning of mold from artifacts. Success has been found using 1,4 –dioxane, N,N-dimethylformamide, and pyridine to remove stains (Szczepanowska and Lovett 1992). These were additionally tested to see their effect on the wet and dry tensile strength. They all tested well. It was also determined that short term exposure of paper to the three did not seem to be detrimental to the sizing, which would affect the texture and feel of the paper (Szczepanowska and Lovett 1992).

While some of these fungicides have a fairly good success rate and others do not, all of these chemicals are toxic in some degree to humans. But the problem, as stated by Haines and Kohler (1986) "Even if the perfect, non-hazardous, non-destructive fungicide is found, there is a fallacy in the 'one-shot cure' of fungus problems. Any 'cure' which does not leave a residual toxin and which does not change the conditions for fungus growth is a temporary cure" (Haines and Kohler 1986: 54). Based upon the danger to both the conservator and the public, none of the six above mentioned chemical methods of mold removal are either truly effective or desirable due to the health hazard.

A new technique of treating papers using aminoalkyalkoxysilanes (AAAS) has shown promising fungistatic results (Rakotonirainy et al. 2008; Cheradame 2009). In this technique, AAAS is dissolved into a solvent and deposited onto the cellulose fibers. It works by bonding the surface or the material with a reactive silane coupling agent, creating a surface-active antifungal agent (Rakotonirainy et al. 2008). In preliminary tests, the paper was immersed in an AAAS solution for ten minutes, and allowed it to dry in a humidity free environment. The treated paper was tested against strains of *Aspergillus niger* and *Paecilomyces variotti*, both commonly found in libraries. It inhibited the growth of both strains (Rakotonirainy et al. 2008).

Another potential treatment for mold extermination is gamma radiation. Gamma radiation has been used to sterilize food and surgical equipment for years. It is very efficient in killing mold on all sorts of materials, including paper, without leaving behind the toxic residues of the chemical methods of mold extermination. Gamma rays pass through materials without leaving any residues. This is a significant advantage when compared to other mold treatments, since the handling of books and documents may be done safely immediately after irradiation (Justa and Urban 1991; Adamo et al. 2001; Nyberg 2003; da Silva et al. 2006).

Gamma radiation causes direct damage to cellular DNA through ionization, which causes mutation and the killing of the cell. Indirect effects occur as a result of radiolysis of cellular water, causing the formation of active oxygen species, free radicals, and peroxides, which cause single and double strand DNA breakages (McNamara et al. 2003). Unfortunately, high levels of irradiation produce free radicals that induce chemical and physical changes in the cellulose, causing the breakdown of the cellulose and degradation of the paper (Hunus 1985; Sinco 2000). Through electron nuclear double resonance, it is possible to clarify the reaction processes. This process singles out the free radicals that are found in both the irradiated cellulose and in the cellulosic systems photosensitized in natural conditions to identify the processes at work degrading the paper (Adamo et al. 1998). Ionizing radiation causes chain breakages with lowering of the DP of cellulose (Adamo et al. 1998; Baum 2002). Experiments have shown that the paper loses 25% of its strength or more from high doses of radiation (Silverman et al. 2007).

When using gamma radiation in the treatment of mold, the appropriate level of radiation must be established that kills all the fungi, while causing the least amount of damage to the paper, in order to be considered the minimum amount of radiation exposure necessary (Justa and Urban 1991). Statements about the volume of irradiation needed to be fungicidal vary, and there are conflicting reports about the quantity that damages cellulosic materials (Haines and Kohler 1986). Studies indicate that the effects of individual radiation exposures add up, and consequently, using small doses of radiation repeatedly to disinfect of books and papers is not recommended (Nyberg 2003).

There are several minimum amounts suggested in the literature. The highest level of irradiation that was tested was 20 kGy (kilogray: one gray is defined as the absorption of one joule of ionizing radiation by one kilogram of matter) by Tomazello and Wiendl (1995) in their experiments. They found that this dose caused obvious damage to the paper. The experiments were conducted to discover if the different stages of mold growth were equally affected by radiation. They found that mold has higher resistancy to gamma radiation after reaching dormancy (Tomazello and Wiendl 1995). Gonzalez, Calvo, and Kairiyama, in their article, "Gamma Radiation for Preservation of Biologically Damaged Paper," found that a 14.4 kGy total dose (over the course of an hour), at room temperature in the presence of air proved to be too low to produce chain ruptures in cellulose polymers to a degree that could substantially affect the mechanical properties of paper (Gonzalez, Calvo, and Kairiyama 2002). They found that because the irradiation time was short, the possibilities of oxidative degradation induced by radiation were limited. Other pages from the same moldy source were submitted to UV accelerated aging for seven days. They tested the ability of both papers to absorb energy when subjected to stress, as expressed by the tensile energy absorption (TEA), which is related to the paper strength and its ability to tolerate stressing or strain. They found that there was no discernable damage caused by gamma radiation to the moldy papers, while the UV accelerated aging caused significant damage (Gonzalez, Calvo, and Kairiyama 2002). Optical microscopy detected no differences in fiber structure between the control and irradiated samples. Other scientists found that doses above 8 kGy can seriously damage historic paper (Justa and Urban 1991), while others found that mechanical tests of paper submitted to irradiation doses up to 10 kGy did not seem affected by this treatment (Adamo et al. 1998).

Some researchers suggest that using heat in conjunction with gamma radiation may be the most effective way to kill mold (Hunus 1985; Justa and Urban 1991; Nyberg 2003). Hunus (1985), a department head of laboratories at the State Central Archives of the Slovak Socialist Republic, stated that they determined that it was possible to kill four types of molds- *Aspergillus flavus, Penicillium spinulosum, Chartonium globosum,* and *Aspergillus nig*er with a dose of 6 kGy. By raising the temperature to 60°C, Hunus found that he could reduce the minimum effective radiation dose to 0.5 kGy. Justa and Urban recommend a temperature of 50°C and 95% humidity for 24 hours prior to irradiation, which was found to lower the necessary amount of radiation for eradication. The humidity brings the mold out of its dormant, more resistant state (Justa and Urban 1991). They found that maximum of only 4 kGy was needed for eradication of mold, when the paper is heated to 50ºC with 95% humidity during irradation (Justa and Urban 1991). The heat and humidity allowed a dramatic decrease in minimum effective dosage, and caused the total destruction of molds without harmful effect to paper, parchment, and books (Hunus 1985; Justa and Urban 1991).

The main reason that the irradiation of paper is not widely accepted is because it is believed to cause excessive damage to the paper (Tomazello and Wiendl 1995; Nyberg 2003). Other arguments against gamma radiation often include the cost, when in point of fact, the cost is much lower than that of fumigation. Another problem in the acceptance of irradiation as a treatment is ignorance. When people hear the word "radiation," they instantly have a negative reaction. Radiation treatments for mold are often overlooked simply because of the lack of knowledge of the process on the part of the conservator or curator.

Radiation is very successful in the treatment of mold, without the toxins of the chemical treatments, but will not it return the paper to its previous strength. Currently, the United States Postal Service has been using electron beam radiation at dosages up to 56 kGy to sanitize the mail going to 202XX-205XX zip codes, which includes the mail sent to government officials and the Library of Congress (Environmental Protection Agency 2010). This has been done to sterilize the potentially dangerous mail that may contain biohazards. The irradiated mail is discolored and brittle, and the severity of these effects seems to be related to the dosage level (Environmental Protection Agency 2010). The effect of these high levels of radiation cause breakages of the chemical bonds in the paper, inducing very rapid deterioration of the paper. Also, not everything that is mailed is exclusively paper, and the effects of the radiation on the inks or other items within the mail have not been evaluated.

While the conservation community is undecided about what role gamma radiation should play in the eradication of mold, the experiments conducted by conservation scientists seem valid. The majority of the sources found in the literature on the conservation of moldy paper and books reviewed here recommend that gamma radiation, used in the minimal amount necessary to kill the mold, is far less dangerous to the material than the mold itself. Additionally, radiation was found to be more effective and less dangerous than the other mechanical and chemical treatments listed above.

In conclusion, of all of the methods and treatments prescribed for mold eradication, there is not one that does not have faults and hazards. Mechanical techniques do little to nothing to cure the larger problem of mold infestation. Chemical treatments require costly equipment, chemicals, and highly trained technicians. While some are very effective, like EtO, the risk to the conservator and those who will be exposed to the material after treatment is too high. Gamma radiation can have its problems if used in too high a dosage, but in cases of serious mold damage, it is clearly the most efficient, cheapest, and the safest of the established methods. Still, it is not perfect, and researches argue over the amount of damage to the materials in the long term. The conservation world is wary of treating infested books and documents with radiation, but sometimes nothing works better (Sinco 2000). Radiation seems to be the best method, if the loss of strength could rectified. None of the treatments provided above are perfect, but with the right combination of techniques, the paper will be preserved mold-free.

Internal Acidity of Paper

The third type of paper damage examined here is paper deteriorating as a result of internal acidity. This type of damage is not caused by a single event, unlike the two problems explored above. Internal acidity begins decaying the paper the day it was made. While some of the earliest Western papers seem to have very few problems with internal acidity, as later papermaking became more efficient, more problems with internal acidity became present (Hunter 1947, 1974; Baty et al. 2010).

The acid stored in the paper causes yellowing, brittleness, and general loss of strength as a result of hydrolytic reactions, oxidative processes, and thermal degradation of cellulose (Giorgi et al. 2002). The loss of strength is not well understood, but is thought to be a result of a weakening of the fiber-to-fiber bonds and structural changes in the fibers themselves (Casey 1980; Roberts 1996; Baty et al. 2010). It is also noted that accelerated aged papers have an increase in stiffness. This indicates that either cross-linking or an increase in crystallinity has occurred, since the cellulose chains in the flexible amorphous regions of fibrils become more ordered and crystalline, held in place by hydrogen bonds between the cellulose chains (Casey 1980; van der Reyden 1992).

There are many causes for this form of damage. To begin with, paper is not pure cellulose. Since the fibers used in papermaking come from an organic source, other compounds are present within the plant. During pulping and refining, methods are used to attempt to remove as many of these as seen necessary for the desired type of paper to be produced, but there are always some residues left behind (Roberts 1996). Acidity can be derived from many other sources involved in paper making, including the bleach left in the pulp, the acidic gases in the atmosphere, the presence of organic acids, and the use of sizing agents and coating materials in and on the paper (Casey 1980). For instance, a common additive for sizing in the past was aluminum sulfate, called "papermakers alum," which is unintentionally a source of acidity in paper (Baty et al. 2010). Other acids found in paper with lignin content can include formic, acedic, lactic, succinic, glycolic, oxalic, vanillic, furoic and ferulic acids among others (Shahani and Harrison 2002).

Other problems can accelerate acid issues within paper. The amount of humidity and its fluctuation, heat, light exposure, and the composition of the air increase the rates of oxidation and hydrolysis, especially if all four are present (Baty et al. 2010). Air pollution, containing air-born sulfur (the major component of smog and acid rain), is a key contributor to the degradation of paper, and studies have found paper stored in industrial areas is at higher risk for this type of degradation (Baty et al. 2010). Additionally, the inks (iron gall ink especially) and the media used on paper can contribute high levels of acid. Also, paper acquires additional acids from contact during handling (Casey 1980).

The acidity of paper is determined as the amount of water-soluble acidity or the hydrogen-ion concentration of the paper extract, which is more indicative of the stability of the paper than the total acidity (Casey 1980). The pH of the paper is determined through cold water extraction, by the guidelines established by the TAPPI T509 cold water extraction test. One gram of paper is macerated into 20ml of distilled water at room temperature (20-30°C) with 50ml added and allowed to sit for an hour. Hot water extraction is conducted at 95-100°C for the same length of time. Any paper with less than a pH of 6.0 is considered to be in danger of degradation (Cheradame, Ipert, and Rousset 2003).

Deacidification is a conservation technique that seeks to treat a paper-based object to neutralize the acid content to prolong its useful life (Baty et al. 2010). Any form of deacidification should be conducted only on an at-risk paper: paper badly enough damaged by acidity that it is discolored and/or compromised in strength. Damage caused by internal acidity is widespread, and many papers and books are at risk. For instance, during survey of the collections held by the Library of Congress, it was found that 25% of their books were so brittle that they would likely fail when folded (Baty et al. 2010). Other estimates state that 40% of the books held by libraries are at risk (Cheradame, Ipert, and Rousset 2003). Replacement with other copies of the same book is not a viable option, since most books are printed only one time using the same type paper and ink, therefore, with the same inherent problems. Additionally, the cost of microfilming a badly degraded book is 500 times more than the cost of microfilming a book that can be easily handled (Ipert, Rousset, and Cheradame 2005). As a result, there has been much investigation into deacidification treatments.

The goal of any deacidification process is the raising of the pH to an alkaline state, and the addition of an alkaline reserve, to combat any further acidic production. For a book to be submitted to the Library of Congress as deacidified, the process used must have raised the pH level of treated paper to the acceptable range between pH 6.8 and pH 10.4, and to have achieved a minimum alkaline reserve of 1.5% or more. The process should extend the useful life of paper (measured by fold endurance after accelerated aging) by over 300% (Library of Congress 2004). Giorgi et al., in their article," A New Method for Paper Deacidification Based on Calcium Hydroxide Dispersed in Nonaqueous Media," state that deacidification processes should:

- Neutralize the acid without dismantling a bound book
- Eliminate of any chemically active by-products
- Allow the formation of thermodynamically stable by-products which may act as an alkaline reserve against hydrolysis
- Provide a complete and homogeneous process of deacidification
- Possess no chemical inactivity with respect to the pigments or dyes used for inks and printing
- Provide a process of low toxicity of the deacidifying agent and solvents with environmentally friendly reagents and products for safety
- Be a simple and inexpensive process (Giorgi et al. 2002).

The most common and inexpensive deacidification technique is to wash the paper in an aqueous solution. Washing serves to swell paper fibers, and as a result, dislodges or dissolves impurities and many acidic compounds. The washing of paper is conducted in order to clean, neutralize acidity, and possibly deposit an alkaline reserve agent (van der Reyden 1992; Baty et al. 2010). This can be done in one step (washing with an alkaline buffer) or in two steps (first neutralizing the acid by washing and then depositing an alkaline reserve) (Baty et al. 2010). It is thought that depositing an alkali agent will inhibit or slow future acidic reactions, since the acid will react with the agent and not the cellulose. In one study, it was found that when a paper with high internal acidity was washed (with no additional additives), and then it was submitted to accelerated aging and compared to a control. The washed paper maintained a greater DP than the unwashed control (Burgess, Duffy and Tse 1990). Since the paper was extremely acidic, the soluble acids were removed during washing, and as a consequence, the washed fibers underwent less acid catalyzed hydrolysis during the accelerated aging than the unwashed control (Burgess, Duffy and Tse 1990).

Calcium carbonate (CaCO3) and magnesium carbonate (MgCO3) are the most often used deacidification agents, because of their chemical simplicity, low cost, high brightness, and their suitability to perform as fillers (Baty et al. 2010). Magnesium carbonate imparts a higher pH, but it has been found that magnesium compounds cause an accelerated aging of pure cellulose. Calcium carbonate buffers in a more moderate fashion, and it usually contains some residual calcium hydroxide from its reactions, which is also seen as a beneficial alkali agent (Baty et al. 2010). Neither is very soluble in water, but some will go into suspension. Other aqueous solutions that have been used include:

- Calcium hydroxide $Ca(OH)_2$. This forms a saturated solution with a pH around 10-12.4 (AIC Wiki 2010).
- Calcium bicarbonate. $Ca(HCO_3)_2$ The pH varies from 6.25-10.25 in a saturated aqueous solution. Others state the pH will not exceed 8.1 (Baty et al. 2010)
- Magnesium bicarbonate. $Mg(HCO_3)_2$. The pH of the solution as applied ranges from 6.5 to 8 depending on age and concentration (AIC Wiki 2010).
- Barium hydroxide. $Ba(OH)_2$. Range can exceed pH 10, and it provides a low alkaline reserve with the yellowing of paper and gritting observed after aging (Baty et al. 2010). Barium compounds are highly poisonous. One gram of barium carbonate (the residual alkali in this process) if ingested is fatal to an adult. Barium hydroxide-treated material should be so marked and handled with extreme care. The pH of the stock solution is around 12 (AIC Wiki 2010).

- Magnesium acetate. $Mg(OOCCH_3)_2$. Both the neutralization reaction and the conversion to the carbonate produce volatile acetic acid, which continues to be generated in treated paper. pH of 6.5-7 (AIC Wiki 2010).
- Calcium acetate $Ca(CH_3COO)_2$. Acetic acid is produced in treated paper. pH of 6.3-9.6 (AIC Wiki 2010).
- Calcium chloride. $CaCl_2$. Often used as a desiccant. pH of 8-9.
- Ammonium carbonate. $(NH_4)_2CO_3$. Mixture of ammonium bicarbonate (NH_4HCO_3) and ammonium carbonate (NH_2COONH_4). pH of 9 (AIC Wiki 2010).
- Borax (sodium borate, sodium tetraborate). $Na_2B_4O_7$. The saturated solution (6.25% w/v) has a pH of 9.5; a 0.01M solution has a pH of 9.2. A 4% (w/v) solution has been employed for alkalizing. This causes a sharp decrease in DP and pronounced yellowing of paper (Baty et al. 2010)
- Ammonia water (ammonium hydroxide). NH_4OH. Concentrated solution is pH 12. For use in neutralization it is diluted to desired pH with purified water. Ammonia water leaves no residual alkaline reserve (AIC Wiki 2010).

There are inherent problems with these treatments. As discussed earlier in the chapter, paper suffers substantially when it gets wet, reducing it to retaining only 3 to 8% of its original tensile strength (Roberts 1996). It must be carefully handled while wet and then laboriously dried. The unintended consequence of washing is that it may remove desired components, which can affect paper stability and cause both a loss of composition and a change in the opacity and feel of the paper. (Burgess, Duffy, and Tse 1990). As with waterlogged paper, the method used in drying the paper once it has undergone an aqueous treatment is very important, and can make a difference in its strength. It is disputed among conservation scientists whether the strength lost during washing is compensated by the removal of acidic compounds (Moropoulou and Zervos 2003; Baty et al. 2010).

At a higher pH (pH 8 and above) the DP decreases more rapidly, implying that an alkaline medium has a catalytic effect on the hydrolysis of the glucosidic bond (Margutti et al. 2001). Other studies have shown that there is a potential for harm if the pH is excessively high (Baty et al. 2010). In alkaline conditions, the "peeling reaction," that breaks one anyhdroglucose unit from the reducing end, can be expected in deacidifided papers (Baty et al. 2010). Furthermore, a high concentration of an alkaline can discolor the paper (van der Reyden 1992).

There are other procedures using aqueous solutions that are proprietarily named and have specific guidelines. The Vienna Process is usually performed on unbound newspapers, which are then bound after their treatment (Baty et al. 2010). The materials are immersed in an aqueous solution to deposit an alkali and a strengthening agent, such as methyl cellulose, and then freeze-dried (Baty et al. 2010). The Bückeburg Procedure is a three component system that uses magnesium bicarbonate (alkali agent), methyl cellulose (strengthening agent), and Mesitol NBS and Rewin EL (cationic and anionic fixatives) in an aqueous solution (Baty et al. 2010). This solution can be used for mass deacidification of single sheets. Using a Neschen C-900 automated deacidification unit, this system claims to be able to deacidify 400 single sheets of paper in an hour (Baty et al. 2010).

There has also been an examination of adding gelatin to buffer the paper. This idea was based upon the use of gelatin as a sizing agent in historic papers. In experiments, it was shown that Whatman filter paper (100% cotton cellulose fibers) treated with gelatin did not degrade as quickly as the controls, when subjected to artificial aging and cycling humidity (Baty and Barrett 2007). Baty and Barrett (2007) suggest that the buffering capacity of the carboxyl side chains in gelatin may be effective at protecting "at risk" papers. They recommend this treatment as a part of the decision to re-size papers following other deacidification techniques, such as washing and bleaching or other techniques. Other external sizes have been recommended, following aqueous deacidification techniques, to impart strength. Starch was originally used in Arabic papers as a sizing agent (Bloom 2001). Other cellulose derivatives, like methyl cellulose, have been used in this capacity because of their similarity to cellulose for stability, and their ability to impart strength to the treated paper. Several authors suggest their use in conjunction with an aqueous solution and an alkaline agent (Sundholm and Tahvanainen 2003; Zervos 2007; Sonoda et al. 2009; Baty et al. 2010). Other suggestions include using polyvinyl alcohol (PVAl) in combination with Borax as an alkaline buffering agent to increase strength (Basta 2004).

These treatments work on individual papers, but the majority of at-risk paper is in bound books that cannot be efficiently washed in an aqueous solution for several reasons. First, the bindings and covers cannot be washed. Second, it is not advised to wash several sheets together, let alone an entire book. As each sheet of paper expands, it will warp the others and will either destroy any binding material (string, thread or glue) or will tear away from it. Third, drying a book is incredibly problematic, as previously described, and the results are not satisfactory. There are other reasons, but suffice to say, the only way to wash a book is to remove the binding and cover and wash the pages individually, dry them, and then rebind the book. Some have tried to wash books, which were then dried by interleaving materials and pressing in the presence of a fan to circulate air (Minter 2002). The results show less distortion than anticipated, but distortion none the less.

Other techniques have been developed to address the problem of deacidifing books; the most popular use non-aqueous methods. These come in three main classes: liquid solutions, liquid suspension, and gas phase treatments. There are several proprietary techniques used worldwide. Since, so much of the world's paper is at risk from acidic compounds, deacidification, especially mass deacidification of many items at once, has become a lucrative endeavor for some conservation specialists.

The Wei T'o method is a non-aqueous mass deacidification process which uses a liquid alkaline agent in a solvent. Originally, the process used magnesium methoxide, but it has been refined through the use of methoxymagnesum methylcarbonate (Baty et al. 2010). Originally, the solvent was freon, but due to environmental concerns it has been switched to a hydroxychlorofluoro compound. The major disadvantage with this treatment is that it can react with certain inks (Giorgi et al. 2002).

The FMC process uses magnesium butyl glycolate dissolved in a liquid solvent, such as heptane (Baty et al. 2010). This process seems successful in depositing an alkaline reserve, but it has been reported that the treatment was not always uniform and not as successful as other treatments (Baty et al. 2010). Promoters of this process stated that it could strengthen the paper fibers, but there is no evidence of this in the literature (Baty et al. 2010).

The Battelle method uses magnesium and titanium ethoxide in liquid hexamethyldisiloxane (Cheradame 2009). This results in magnesium and titanium hydroxides being formed, which work as an alkaline reservoir. The mechanical resistance of the treated paper remained unaltered after 100 days of artificial aging. The toxicity level is rather low and therefore environmentally friendly. (Giorgi et al. 2002). The final pH is 7-9, but in some cases it exceeded 9 (Baty et al. 2010). This process is also known as Papersave®.

The Bookkeeper® method is a liquid method that deacidifies paper by the deposition of sub-micron sized particles of magnesium oxide into the paper matrix. When the Bookkeeper® solution is sprayed on a sheet of paper, the carrier evaporates, leaving behind the fine particles of magnesium oxide and the surfactant in the paper. Magnesium oxide reacts with water to form magnesium hydroxide, a known deacidificant. Magnesium hydroxide reacts with acids in the paper to form magnesium salts (Stauderman, Brückle, and Bischoff 1996). The particles are small enough that they impregnate the paper, which are held to the paper as a result of the electrostatic forces within the paper and do not affect the features of the paper (Giorgi et al. 2002). It has been suggested that some papers treated with a magnesium-based deacidificant have an increased uptake of air pollutants, resulting in poor mechanical performance when compared to untreated paper (Banik et al. 1993). Other problems occurred in the aesthetic qualities of the paper; the colors appeared changed and a chalky-white precipitate was found on treated items (Stauderman, Brückle, and Bischoff 1996). Additionally, if the solution was only sprayed on one side, it only penetrated that side, resulting different pH on each side (Stauderman, Brückle, and Bischoff 1996). This process is primarily used in American libraries as a preventative treatment (Cheradame 2009) and is evaluated on the Library of Congress's webpage (Library of Congress 2004).

The CSC Booksaver® process takes place within a specially designed treatment chamber. The book or paper is sprayed with a reagent composed of carbonated magnesium di-n-propylate, 1,1,1,2,3,3,3 heptaflouropropane and n-propanol. The treatment chamber is fully automated and has pre-programmed cycles. The process consists of the deposition of magnesium carbonate at 40°C (Cheradame 2009). The positive of this treatment is that the pH is raised to between 7-10 pH with an alkaline reserve (Meese 2005). There a few problems with this process, including stains, ink bleed and movement, faded pictures and stuck together sheets, but this occurred in only a few cases (3.1%) (Meese 2005). It was not discussed, but heating to 40°C would also have negative side effects because it would cause accelerated aging.

All of the above non-aqueous processes are in use today by conservation companies and libraries. There are drawbacks to each method, and different groups and researchers prefer one treatment over another. Moreover, none of these processes do anything to increase the mechanical properties of strength n or durability of the paper (Cheradame 2009).

A new liquid phase deacidification technique has been recently introduced using aminoalkyalkoxysilanes (AAAS). This treatment raises the pH to a range of 8-10, and provides sufficient alkaline reserve (Ipert, Cheradame, and Rousset 2005; Cheradame

2009; Baty et al. 2010). The amine-base functions within the solution to provide deacidification, because the alkaline agent becomes covalently bound to the paper at a molecular level. It also acts as a polymeric strengthener, by reinforcing the cellulosic fiber matrix through an interpenetrating polymer network (Cheradame 2009). The problem with this treatment is that the alkaline reserve can become completely reacted, causing the pH decreased to below acceptable levels.

Gas phase treatments, like other non-aqueous treatments, do not remove acids from the paper. They seek to neutralize the acids by depositing alkaline agents. The gas phase process is attractive, since it would avoid using solvents and drying, and would be relatively be simple and efficient to conduct (Charedeme, Ipert, and Rousset 2003). In the 1950's, ammonia gas was used, but the deacidification was found to be temporary, so it was abandoned (Charedeme, Ipert, and Rousset 2003). Diethyl zinc (DEZ) has been proposed more recently. This process deposits ZnO as an alkaline buffer, providing a pH of 7.5-9.5 (Baty et al. 2010). There are a few downsides, because in some tests, ink bleed and bad odors were reported (Baty et al. 2010). Additionally, the use of DEZ is potentially hazardous, because it reacts violently with water and ignites in the air in an exothermic reaction (Baty et al. 2010). The paper must be very dry. This process requires specific facilities, and should not be undertaken by anyone other than a specialist (Cheradame, Ipert, and Rousset 2003). Other experiments with gas phase application have attempted to use ammonia salts in conjunction with silazanes and silanes, but the results were unsatisfactory (Charedeme, Ipert, and Rousset 2003).

Another type of gas phase deacidification technique that has been recently introduced uses aminosilanes in a non-aqueous solution. Amine-based functions provide deacidification, if they can be bound within the fiber network. The treatment suggested the use of 3-amino propyl trimethoxy silane (ATMS), which increased the pH and left an alkali agent in the paper (Rousset, Ipert and Cheradame 2004). Unfortunately, during aging, the alkaline reserve seems to have completely reacted, because the pH decreased to below acceptable levels. This is thought to be the result of the process not being able to deposit a sufficient reserve. It did impart strength to the paper; in some cases doubling the breaking length and more than doubling the fold endurance. The tests did not specifically designate whether the strength was gained in the fibers or in the interfiber bonding network, but that the strength of the paper improved.

A third type of gas phase process is the forced air or Libertec® process. It uses air to blow a deacidifing agent, like sub-micron particles of magnesium oxide and magnesium carbonate, against the paper (Baty et al. 2010). This conservative method claims to provide a thorough distribution of the alkali. Realistically, the alkali agent deposits onto the surface of the paper, without actually penetrating it (Baty et al. 2010). If the paper is handled or exposed for long periods of time, one can assume that it would simply fall off the paper.

A non-invasive deacidification process that does not fit into the categories of liquid or gas is interleaving books with thin pieces of alkaline paper containing calcium carbonate. There is evidence that interleaving can influence the pH of the paper of a book up to several pages in thickness. It is thought that neutralization occurs with the alkaline paper and the humidity in the air, and maybe even more effective in very humid conditions (Baty et al. 2010).

There are inherent expenses with each type of process, whether in labor or in equipment and materials. In the 1990's the cost of mass deacidification using the BookKeeper® method was between $6.00 and $10.00 per book, which is cheaper than the estimates for photocopying ($65) or microfilming ($250) (Harvard 1991). Currently, using the Booksaver® process costs about $17.00 a book (Baty et al. 2010).

All of the deacidification methods seek to prolong the useful life of the book. Each method has positives and negatives. Washing paper with an alkaline agent provides the best deacidification, since the acids are removed and a reserve is introduced into the matrix of the paper. Unfortunately, washing weakens the paper, and it is almost impossible to wash a bound book. The gas phase processes would be ideal if they actually worked, because they would offer the easiest application of an alkaline agent. The non aqueous methods are most commonly used in the deacidification of bound books. Each process has some inherent faults, but they generally work. Regrettably, they do nothing to strengthen the weakened paper. The new method of AAAS provides the best results: deacidifing and endowing strength. This is a new process and should be tested further, but it has the potential to provide the best results. The hope of all of these processes is to provide a longer life for the paper. If the process is tested to ensure that it will not damage any of the components of the book or paper, and it will lengthen the useful life of the book or paper, it should be considered a valid technique of deacidification.

Conclusion

Paper degradation can be caused by a number of different conditions. The chemical reactions of hydrolysis, oxidation, and cross-linking damage paper internally, which leads to the degradation of the paper. These reactions can be caused or continued by waterlogging, mold, and internal acidity. Further problems can arise from these actions, including a general weakening of the paper and a diminished ascetic quality.

When paper becomes waterlogged, there are few possible options; the choices made by the conservator may be dictated by the quantity and type of the material. Paper is weakened by the action of the waterlogging and its mechanical and chemical effects, and none of the recommended treatments can restore the paper to its original strength or integrity. The best treatment scenario attempts to ensure that the paper is not a loss.

Mold causes the deterioration of paper as a result of a biological agent. It degrades the paper through it digestion of the cellulose, and the byproducts of the digestion can accelerate the chemical methods of degradation. An ideal cure for mold does not exist. The chemical methods may be effective on the mold, but the toxicity retained by the treated papers makes handling the paper unadvisable. Nuclear irradiation treatment is the most effective method, as it results in killing the mold and does not impart additional toxicity. There is still a potential risk to humans from the byproducts of a mold infestation, but with thorough mechanical cleaning, these toxins can be removed. Even though nuclear radiation is the best treatment for a mold infestation, the irradiated paper loses much of its original strength. To begin with, the paper has already lost strength from the conditions that caused the mold: waterlogging or high humidity.

Then, the paper loses more strength from the mold infestation and the subsequent drying procedure. After that, the paper is irradiated, causing an additional loss of strength. Even in its new, mold-free state, that paper is much weakened from all of these issues. If strength could be returned to the paper after these procedures, it would be considered more successful in its treatment.

Internal acidity is a major problem in any collection of paper artifacts, but this is especially true in libraries, whose collections may include very low quality paper in unstable environmental conditions. The washing of individual pages of paper may be possible, but the huge numbers of bound books that are at risk are unable to undergo this treatment. Not that washing is perfect but it can remove some of the acids, while adding an alkali agent to the matrix of the paper to combat other acids that are present. Most of the deacidification techniques seem viable, but they do not actually remove acidic compounds, and only seek to neutralize those present. Based upon the chemical reactions of the neutralization processes, there may be unintentional consequences from these reactions. Deacidification by the addition of a basic agent serves to place –OH ions within the matrix. These may halt hydrolysis, but they may increase the rate of oxidation as a result, which subsequently may cause unintentional hydrolysis from the release of +H ions, resuming hydrolytic reactions. An ideal deacidification treatment would both neutralize the acidic groups by introducing an alkali agent, while also strengthening the cellulose chains. This could be accomplished by chemically closing the potential avenues for oxidation and hydrolysis, by stabilizing the cellulose and adding strength to the fiber matrix.

All of the methods of treatment are designed to save the paper artifact. Weakened paper is better than no paper at all. When a group of paper artifacts become damaged from any of the three major problems of paper deterioration, any treatment that adds useful life to the artifacts should be considered a valid conservation technique. Still, some techniques are more valid than others, and it is up to the informed conservator to make choices that will best insure the longevity of the artifacts at risk.

CHAPTER V

PASSIVATION POLYMERS

This chapter focuses on the uses of passivation polymers and how they can be applied to paper conservation. For many years, the Department of Anthropology at Texas A&M University has been at the forefront of archaeological waterlogged artifact conservation, and object conservation in general, advancing the science of conservation. One of these advancements is the use of a specific polymer technology, known as passivation polymer technology, in the conservation of organic objects. Passivation polymers are silicone-based functional polymers that strengthen the matrix of an organic artifact. In addition to thoroughly conserving and preserving the treated artifact, this method has been shown to provide additional strength and resiliency to the damaged object. Objects that would have been previously conserved using other methods, requiring long conservation treatment and special curation or display conditions after conservation, can be conserved relatively quickly and displayed or curated with little special treatment.

The use of organic polymers in the treatment of waterlogged wood was first suggested in 1978 at the Working Group on Waterlogged Wood of the ICOM (International Council of Museums) in Zagreb (Pearson 1981). C. Wayne Smith and Donny L. Hamilton of Texas A&M University and Jerome Klosowski of Dow Corning have received several patents for their work with passivation polymers and artifacts, as well as for other applications, such as medical specimen preservation (Smith and

Hamilton 1998, 2000a, 2000b, 2002, 2004, 2005). Passivation polymers were first used to conserve archaeological artifacts in 1995, and have been especially successful in the treatment of waterlogged and damaged wood and fabric, both of which are cellulose-based organics.

Passivation polymers are functional polymers that work on a cellular and molecular level. They are not a simple consolidant or a bulking agent. They are used to coat and impregnate cells with materials that react with the walls in order to prevent cellular or other collapse (Klosowski 2003). On the molecular level, they work to conserve a damaged artifact by placing a substance on the molecular structure that reacts with carbonals (-COH) (Klosowski 2003). Reactive silanes, acting as crosslinkers, like the trifunctional methyltrimethoxysilane ($MeSi(OCH^3)$ also known as MTMS) react to the cell walls, to each other, and to the polymers within the matrix of the artifact, providing a pliable, flexible result (Klosowski 2003). They work well in combination with silanol (-SiOH) ended polymers, to add strength to the structures of the artifact without rigidity. The most often used silanol or silicone oil is dimethyl siloxane, a hydroxyl-terminated polymer, with up to a 5% dimethyl cyclosiloxane. It has different viscosities, ranging from 5-20000 CST (centistokes) providing a range of solutions.

One of the best features of this treatment is that the solutions of polymers can be tailored to suit the artifact undergoing conservation (Klosowski 2003). For instance, if the artifact should be pliable and flexible, like leather, it would require a higher weight molecular polymer. If the artifact should be very strong and stiff, like a wooden timber, it would require a stiffer, stronger resin, and would use a lower weight polymer. Mixing these chemicals is both an art and a science. The science can be found in the application of the chemicals, but it also takes an artistic touch to choose the right combination of chemicals to provide the desired traits for such hard to conserve items as skin, hair, glass, wood, or leather (Klosowski 2003).

The conservation of many types of artifacts can require a catalyst to hasten and complete the reaction (Klosowski 2003). The most commonly used is dibutyltindiacetate (DBTA). There are several different catalysts available, but they are all tin-based. Some encourage faster or slower reaction times. Some oxidize quickly, while others are slower, and therefore, penetrate deeper. The speed of the reaction can be encouraged by the addition of heat. The catalyst can be introduced through either gas diffusion or direct application to the artifact (Smith 2003). Not all artifacts require a catalyst to complete the reaction; especially if the artifact is very thin and total penetration is easily accomplished.

When using this treatment, the artifacts must be dry, as passivation polymers cannot be used in combination with water. If the artifact is wet, the water trapped in the cells of the artifact must be replaced with a medium less reactive to the polymers. Organic solvents, like ethanol or acetone, are used to dehydrate the artifact through a series of solvent baths. These slowly replace the water, by beginning with ethanol/water baths of increasing percentage, to ethanol/acetone baths, concluding the dehydration in a bath of pure acetone or another solvent, such as ether. The polymer solution then replaces the solvent. This can be conducted by placing the artifact into the polymer solution at ambient pressure or under vacuum pressure over time. The polymer may be applied topically by brushing or by spraying, if the artifact is thin enough to ensure penetration. After complete penetration of the polymer solution into the artifact, it is either placed into a closed environment with a catalyst present or it is exposed to air.

Exposure to the air, and its inherent humidity, of an artifact treated with a polymer/cross-linker solution, completes the reaction and "cures" the artifact. This allows the cross-linker to finish reacting. The following equations demonstrate the cure:

1. The reaction to the cell wall is SiX + HOC $\rightarrow$ SiOC —— + HX X = alkoxy
2. The reaction to the polymers is SiX + HOSI $\rightarrow$ SiOSi —— +HX
3. The reaction with an excess of cross-linker and insufficient water is

   SiX +SiX ø no reaction.
4. Air exposure yields partial hydrolysis followed by condensation:

   a. SiX + HOH $\rightarrow$ SiOH + HX

   b. SiX + SiOH $\rightarrow$ SiOSi + HX (Klosowski 2003: x).

The outcome of this treatment is an artifact that has become more stable than it was in its unconserved state. This treatment is superior to other conservation treatments as not only is the artifact stable, but new strength has been added to the artifact through the polymer resins formed within the structure without adding significant weight. In addition to strength, the artifact is more chemically stable in general as well (Klosowski 2003).

There are many other advantages to using this treatment. While the chemicals themselves are costly, no special equipment is necessary. After treatment, the artifact can be stored in nearly any environment without the need of special considerations for humidity or temperature. The artifact has a level of durability that will allow for travel and exhibition, and it can be handled and archived with ease. Many artifacts can be treated at the same time, with a low investment in labor costs. While a supervisor must be well-trained and have experience working with these chemicals, conservation technicians do not need extensive training to be able to efficiently treat artifacts.

Another advantage in using passivation polymers is that they can be used to treat composite artifacts of different materials. Some individual artifacts are not just organic or inorganic, but oftentimes are composites of both materials. In one case, a basket filled with iron shot recovered from the *La Belle* shipwreck (1687) excavated from the Matagora Bay of Texas needed to be conserved. In its unconserved state, the basket was too fragile to risk the removal of the iron shot. Other methods of conservation would have required very different treatments for both the shot and the basket, requiring their separation prior to conservation. This would have caused the basket to be damaged significantly, which would have required its reconstruction after conservation (if possible). Instead, the basket and the lead shot were treated together with passivation polymers. The polymer conserved and added enough strength to the basket to endure the mechanical removal of the iron shot. The iron shot was undamaged by the passivation polymer conservation process, as the polymer has no chemical effect on metal (Smith 2003).

After experiments and extensive conservation using passivation polymers to conserve organic cellulose-based artifacts, it was logical to investigate their use with severely damaged paper. Using silanes in paper conservation is uncommon, but a few articles suggesting their use have been published. The first "Preservation of Aged Paper by Alkoxysilanes," by Paleos, Mavroyannakis and Cypriotaki (1981) stated that the bursting and tensile strength of the paper improved, while elongation decreased during the use of "Strengthening agent H" manufactured by Wacker Chemie. Its formulation contained alkoxysilane, alkylalkoxysilane and alkypolysiloxane (Paleos, Mavroyannakis and Cypriotaki 1981). More recently, the use of aminoalkyalkoxysilanes (AAAS) as a treatment for deacidification has been suggested (Rousset et al 2004; Ipert et al 2005; Cheradame 2009; Bennevault-Celton et al 2010a, 2010b). Other experiments suggest that AAAS has fungistatic properties (Rakotonirainy et al 2008; Cheradame 2009). But there are many different silanes and silanols that would have different qualities when used in the conservation of paper.

When passivation polymers are combined with cellulose chains, such as those in damaged paper, they act to slow the rates of hydrolysis, oxidation, and crosslinking. As stated before, hydrolysis leads to an increase in the crystallinity of the cellulose, which causes a loss of strength and flexibility. Oxidative reactions are responsible for the yellowing of paper and a loss of strength. Crosslinking is a byproduct of these two reactions, and acts to increase the rate of degradation. By slowing or stopping these reactions, the paper retains more strength over time. Additionally, passivation polymers add strength to the paper matrix by providing a strengthening polymer network. Since they react to the cell walls, to each other, and to the polymers within the matrix of the paper, they form strengthening resins within the fiber matrix, which are believed to be formed as illustrated in Figure 12. Figure 13 shows two ESEM photos: the first is paper before treatment and the second clearly demonstrates the formation of the network of polymer resins between the fibers.

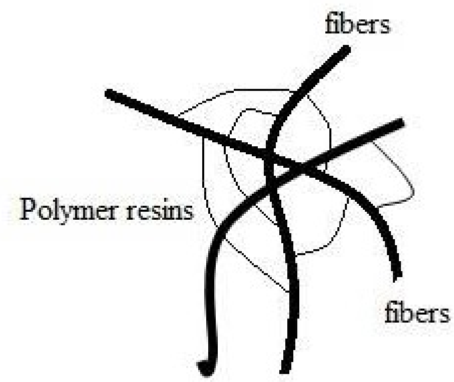


Figure 12. A representation of the network of polymer resins formed between the fibers.

Prior to the experiments and case-studies conducted by the author presented in the next chapter, the Conservation Research Laboratory (CRL) at Texas A&M University had excavated and treated a few paper artifacts recovered from shipwrecks. These were found in conjunction with other organic artifacts, and all were successfully conserved using passivation polymers. From the *La Belle* shipwreck, a box was recovered that contained items wrapped in paper. The entire box was submitted to an initial analysis, and then went through Passivation Polymer treatment prior to opening it. This is a major advantage of the treatment, as the entire contents could be stabilized

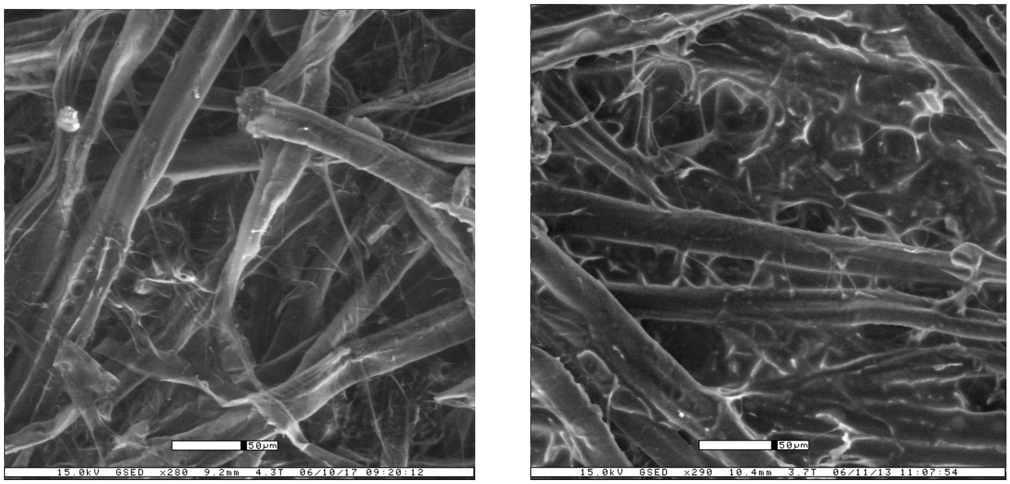


Figure 13. ESEM of paper before and after treatment. These are papers from the same source. The paper on the left is untreated. The paper on the left was treated with passivation polymers. Note the polymer resins formed between fibers.

before the box was excavated. The paper, as seen in Figure 14, would probably have been washed away during the excavation of the box, if it had not been stabilized and conserved prior to its opening (DeWolf 2005). Figure 15, once thought to be leather,

Figure 14. Paper conserved using passivation polymers from the *La Belle* shipwreck. Photo courtesy of the Texas A&M University Conservation Research Laboratory.

Figure 15. Another conserved artifact from the *La Belle* shipwreck. It was thought to be leather, and now thought to be paper highly saturated with sediment. Photo courtesy of the Texas A&M University Conservation Research Laboratory.

now is thought to be paper highly saturated by sediment. It only survived as a result of the treatment.

Other artifacts excavated from *La Belle* include a number of iron knives wrapped in paper. The iron eroded years ago, but thanks to the polymer-conserved paper that they were individually wrapped in, the void the iron left behind could be cast into replica blades that were placed on their surviving wooden handles, seen in Figure 16. (DeWolf 2005). The paper was lost in the casting procedure, but had it not been conserved using passivation polymers, it would not have been possible to cast the blades.

Another example of paper conserved using passivation polymers comes from Carrie Sowden's conservation of items from the wreck of the *Brother Jonathan*, wrecked on July 30, 1865 (Sowden 2006). A large sealed crate was recovered by Deep Sea Research, Inc., under the custodianship of the California State Lands Commission, who concluded that it must be conserved. They contacted CRL, which conserved the crate.

Prior to opening the crate, it was X-rayed and found to contain mostly hardware and other supplies destined for British Columbia. Since the crate was recovered from a

Figure 16. Knives from the *La Belle* Shipwreck. The handles are original, but the blades are cast from the paper that surrounded each individual blade. Photo courtesy of the Texas A&M University Conservation Research Laboratory.

marine environment, it was mandatory to keep it wet prior to treatment. Many of the hardware items were found to be wrapped in paper. The paper wrapped around some packages were found to be in varying states of preservation, ranging from very good, to totally disintegrated, and in some instances, the remains of labels could be seen in the packing paper (Sowden 2006). The intact paper packages were conserved using passivation polymers. They were first put through a standard series of dehydrations baths, after the chlorides were removed. The treatment solution consisted of 65% silicone oil (SFD1) with 35% methyltrimethoxysilane (MTMS) added by volume as a crosslinker. Then, the packages were immersed in the passivation polymer solution. After a suitable time period, the packages were removed from the solution and the excess silicone oil was allowed to drain over a period of several days (Sowden and

Hamilton 2002). After the paper was conserved, it could be carefully handled to reveal the content of the packages. Figure 17 shows the excavation of some plumb bobs from a paper package preserved by the polymer treatment. There was other paper recovered from this box as well, but it did not fare as well since it was not conserved prior to its excavation. In the description of the conservation of some scythes removed from the box, Sowden states, “There was evidence of paper left on these rectangles; however, after exposure to air, the paper quickly disintegrated,” (Sowden 2006: 74).

In this same box, there were many iron items of hardware wrapped in paper. While the iron disintegrated as a result of being underwater, the paper that was wrapped around the items endured and provided a natural mold of the original iron artifacts. As a result of the paper being impregnated with iron particulate, the paper was stronger than it might have been without the iron. That, combined with the addition of strength from the

Figure 17. Unwrapping and cleaning a paper-wrapped package of plumb bobs. Photo courtesy of the Texas A&M University Conservation Research Laboratory.

polymer treatment, caused the paper to retain the imprint of the hardware items enough so that they could be cast in epoxy to replicate the artifact from the molds formed by the paper. Some of the paper preserved the imprint of the artifacts so well, that the makers' mark could be recovered (Sowden 2006). This was only possible as a result of the passivation polymer treatment, because otherwise the paper would not have been strong enough to be able to be used for molds otherwise.

Since these were early examples of using passivation polymers on paper, the specific solution was not tested experimentally before use. The solutions chosen for the conservation of these artifacts contained a large percentage of silicone oil, but since the paper recovered was in particularly bad condition to begin with, conserving quickly was more important than worrying about the texture and color after the fact. Additionally, there were other artifacts present that needed to be conserved requiring a high silicone oil content, so the needs of those artifacts took precedence over the needs of the paper.

The use of silanes is not unknown in paper conservation. The successful conservation of many organic artifacts using a combination of specific silanes and crosslinkers, known as passivation polymers, demonstrates its suitability for the conservation of other cellulose-based artifacts, such as paper. Passivation polymers provide chemical stability and increase the internal strength of the paper by the formation of a polymer network within the paper matrix. In the few instances of paper recovered from waterlogged materials at CRL, the treatment has performed well. Through further experimentation with passivation polymers, it is possible to create a specific solution to fit the needs of the paper, which will continue to stabilize and strengthen the paper, while allowing it to retain more of its specific aesthetic qualities.

CHAPTER VI

PASSIVATION POLYMERS AND PAPER

This chapter focuses on the experiments using passivation polymers in the conservation of paper. The experiments examine the use of the polymer treatment and its effect on the issues of waterlogging, mold, and deacidification. The chapter begins with a discussion of the some of the negatives and positives of using the polymer treatment on paper. This is followed by a review of the experiments using the treatment. The report of each experiment can be found in its entirety in the appendix. The evaluations of the experiments reference the results as discussed in each report. Before discussing each experiment, it should be noted that many of the experiments were replicated and evaluated individually. When the experiments were replicated, the results were the same or very similar, unless noted otherwise.

Before discussing the experiments using passivation polymers, it should be recognized that there are benefits and disadvantages in using passivation polymers in the treatment of paper, as there are in any method. While the treatment provides excellent results, as discussed below, passivation polymer treatment is an invasive, non-reversible process that is best used in situations of damaged paper. In an ideal world, the ethics of conservation mandate that only conservation treatments that are considered by the majority as being reversible should be practiced. Yet, no treatment is truly reversible. None of the previously used methods recommended for the treatment of the three major causes of severe paper degradation outlined within this work are reversible. However, some would argue that some treatments are more invasive than others; for instance, washing paper with water and a mild alkali agent for deacidification is a common practice. Even though it causes a loss of strength, it is considered to be a mild treatment, and it does not dramatically alter the chemistry of the paper. Passivation polymers alter the chemistry of the paper, resulting in a more stabilized chemical structure of the cellulose and a stronger paper matrix from the introduction of a polymer network. This causes an irreversible change in the paper that is beneficial to extend the useful life of paper, which would otherwise be considered a loss due to its damage. Passivation polymers can save what is unsalvageable by other methods and it can treat the untreatable. As Sinco states in his article "The Use of Gamma Rays in Book Conservation," "Well, of course, any treatment—handling a book, fumigating it—will probably cause some sort of damage. If you want to be a total purist, you can just sit and watch the thing rot and weep over it" (Sinco 2000: 38).

Another issue is that passivation polymers can alter some of the qualities of the original. In a few cases, the color of the paper was slightly altered, either darkening slightly or becoming almost imperceptibly more translucent. The texture can change, usually resulting in a smoother surface. If the paper is cockled, folded, or wrinkled, these traits can remain after treatment, and should be addressed prior to treatment. As stated before, passivation polymers should only be used when a question of endurance is at stake. It is better to retain the document in a color or texture slightly different from the damaged original, than to lose it altogether.

Besides the stability and the strength added by the polymer treatment, there are other positives. It seems to render paper unattractive to paper eating insects. If the media on a paper is very friable and seems to be separating from it, silicone oil can act as an adhesive and consolidate the document. It can prevent fading. In instances where the paper has already become fragmented from severe damage that has caused the paper to become brittle or friable, after treatment the fragments are strong enough undergo conventional methods of mounting on rice backing paper.

While the chemicals used in this treatment are expensive, the treatment is relatively fast, and therefore inexpensive in labor and other conservation materials. No additional money needs to be spent on housing or archiving the item in a controlled environment, and it can be easily accessed by the researcher or museum personal. All of the positives of this treatment outweigh the negatives posed by the possibility of losing the document all together.

Experiment 1: Determining the Best Solution of Passivation Polymers

The first experiment using passivation polymers and paper was conducted to determine the best solution of different percentages of polymers and crosslinkers for conserving paper. Since the different chemicals can be mixed in different proportions, many different solutions needed to be prepared and analyzed. Successful application of the polymer mixture will result in a paper that is the least altered in look or feel.

In the first experiment (see Experiment 1 in appendix), different colors of construction paper, printer paper, and butcher paper were selected to be treated with passivation polymers. Five different solutions of methyltrimethoxysilane (MTMS) and silanol or silicone oil (SFD 1 or Si oil) were created by weight. They were 0% MTMS + 100% Si oil; 20% MTMS + 80% Si oil; 60% MTMS + 40% Si oil; 95% MTMS + 5% Si oil and 100% MTMS + 0% Si oil. Each paper was cut into strips and labeled. A control from each was set aside. A strip of each experimental paper was placed into one of the five solutions. They remained in solution for a week. The strips were then removed and blotted over a period of five months, to remove any residual treatment solutions and to be certain that the reaction was finished. Since paper is so thin, it was not necessary to use any catalysis in any of the experiments, and it was not used here. These were compared to the untreated control, using the traits of flexibility, texture, color, folding, and tearing. Folding refers to folding a crease along each strip after treatment. When the control is folded, the crease ridge or compression is not easily felt. If the treatment is successful, the crease will not be easily felt either. This test is conducted to examine the rigidity of the resins formed within the paper and to compare its folding flexibility.

The result of this experiment demonstrated that if an excess of Si oil was used, it would darken the thick construction paper or make the thinner, white papers translucent. The samples that went into the solutions of 0% MTMS + 100% Si oil; 60% MTMS + 40% Si oil; and 20% MTMS + 80% Si oil had too large a concentration of Si oil. These samples were more easily torn and felt waxy and oily. The folded area on each maintained a crease that could still be felt. The paper was flexible, but it felt very weak, and it would easily fold rather than bend. Figure 18 demonstrates how much darker than the control that the paper became from treatment with 0% MTMS + 100% Si oil.

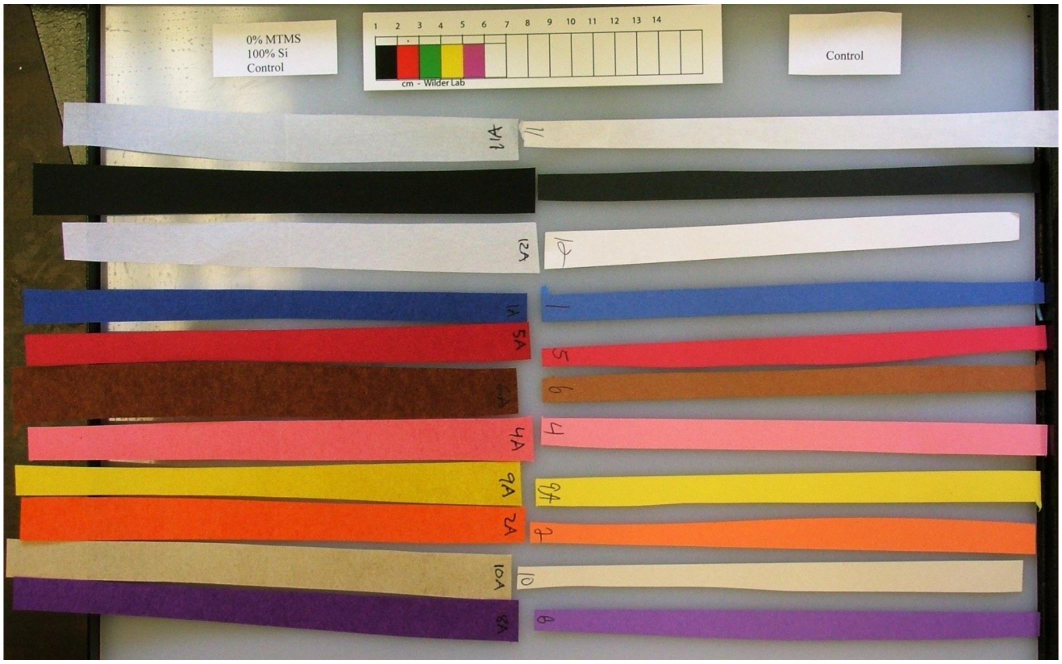


Figure 18. Comparison between the control (right) and treated paper from 0% MTMS-100% Si oil (left). Note the darkening of the treated paper.

The paper that went into the solutions of 100% MTMS + 0% Si oil and 95% MTMS + 5% looked and felt just like the controls. The results of the comparison between the controls and the 95% MTMS + 5% Si oil can be seen in Figure 19 and the result of the comparison of the 100% MTMS + 0% Si oil can be seen Figure 20. The tearing did not seem to be any different. The only difference between the two was that the crease could still be felt after folding the 100% MTMS samples. This is due to the stiffness of the resin formed within the paper matrix. The 95% MTMS solution has just enough Si oil to impart a greater degree of flexibility. As a result of these tests and comparisons, the 95% MTMS + 5% Si oil solution was selected as the best solution compared to the untreated controls.

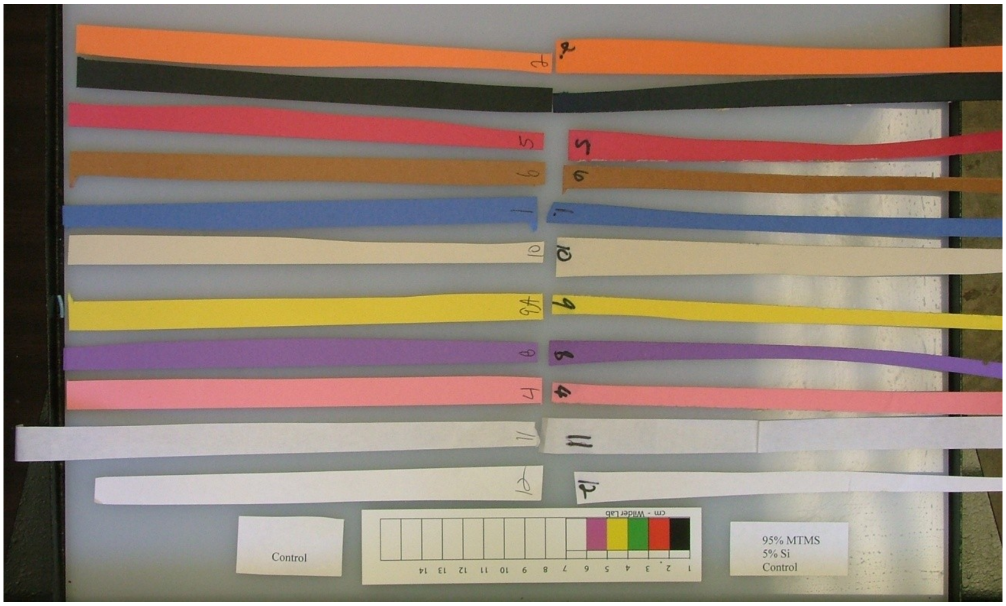


Figure 19. Comparison between the control and treated paper from 95% MTMS + 5% Si oil. The colors are generally the same between the control and the treated.

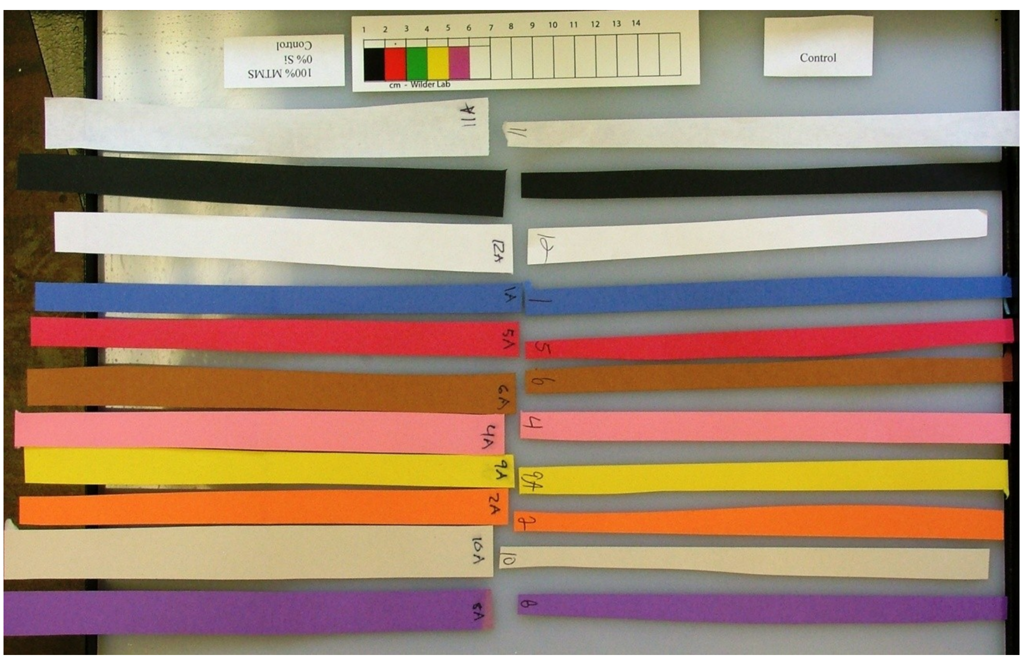


Figure 20. Comparison between the control and treated paper from 100% MTMS + 0% Si oil. The colors are generally the same between the control and the treated.

Experiment 2: The Effect of the Solutions on Weathered Paper

In the second experiment (see Experiment 2 in Appendix A), the same type of construction paper, printer paper, and butcher paper used in Experiment 1 was selected. The difference in this experiment from Experiment 1 is that the paper would be damaged prior to treatment to analyze the effects of the solutions on weakened paper. As discussed before, there are many causes and forms of damage to paper. Knowing in advance that paper artifacts from the Bonfire Memorabilia Collection needed conservation, the paper for the experiment was exposed to the same kind of environment to replicate the type of damage that the Collection paper received from being outdoors in the fall in Texas. The paper artifacts from the Collection had several different medias, such as marker, pencil, and pen, used for their messages. So, as seen in Figure 21, these papers were marked with these as well to examine the effects of the weathering and

Figure 21. The experimental papers prior to being exposed. Pencil, pen, and marker was applied to each to see if they were affected by the weathering or solution.

treatment on the medias.

The damage to the paper was achieved by taping the papers to the outside of a third floor window for two weeks, replicating a similar environment to that which the papers from the Bonfire memorials were exposed. The paper from the memorials and the experimental paper became bleached from sun exposure, deteriorated from rain and wind, and were exposed to other biological agents. The material from the memorials was not exposed during freezing conditions, and as a result the experimental paper was not exposed to freezing conditions either.

Each of the damaged experimental papers was cut into strips and labeled. A control from each was set aside. The experimental paper strips were placed into each solution for a week. They were removed and blotted over a period of five months, to remove any residual treatment solutions and to be certain that the reaction was finished. These were compared to the untreated weathered control papers in flexibility, texture, color, folding, and tearing. Figure 22 shows how much damage the weathered control underwent, compared to the controls. The paper is cockled and feels weaker and softer. It is significantly bleached from sun exposure. The inks have bled slightly and are lightened from sun exposure.

Figure 23 displays the effect of the 0% MTMS + 100% Si oil treatment. The treated strips appear to be in better shape than the weathered controls, since more of the color has returned, but they are more easily torn. When folded the crease remains, and they feel waxy and slick. The ink has bled as well. The samples treated with 20% MTMS + 80% Si oil and 60% MTMS + 40% Si oil had the same appearance and feel, as

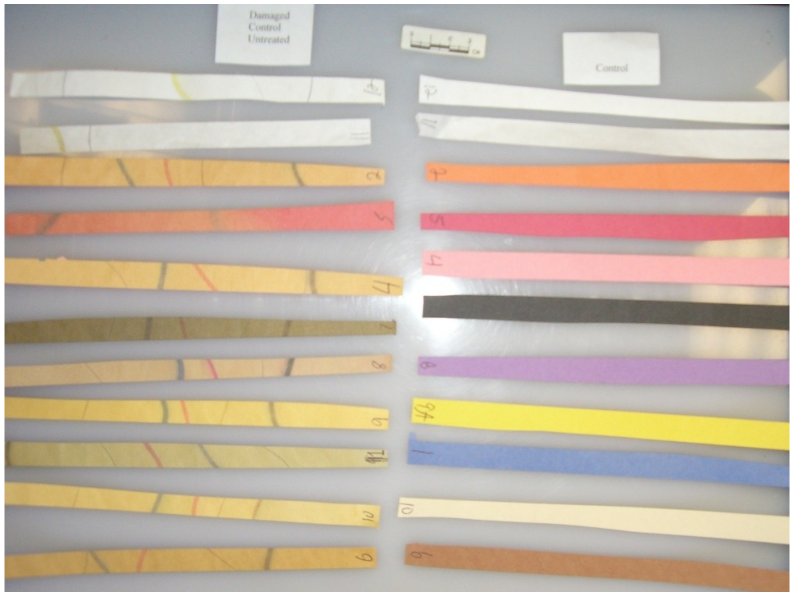


Figure 22. The weathered control versus the original control set of strips.

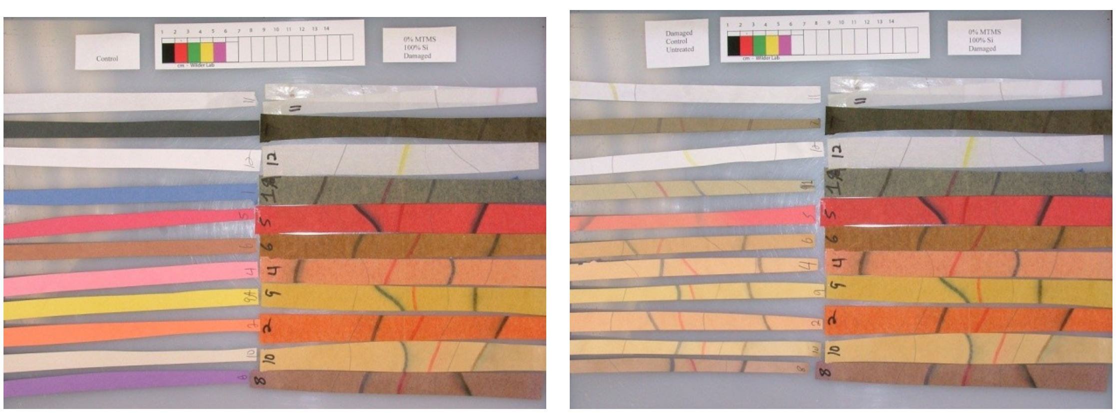


Figure 23. The photo on the left shows the control versus the 100% Si oil treated weathered strips. The photo on the right shows the weathered control versus the treated weathered strips.

those treated with 0% MTMS + 100% Si oil treatment, because there is too high a concentration of Si oil in the solutions.

Figure 24 displays the strips treated with 95% MTMS + 5% Si oil versus the untreated control and the weathered control. This solution provided the best results in this experiment. The treated weathered strips look and feel the same as the untreated strips. They tore in a similar manner. The folding is easier in the treated strip than the untreated. This denotes an increase in strength and flexibility. There does not seem to be any additional ink bleed. The samples treated with 100% MTMS + 0% Si oil looked very similar to these, but the 95% MTMS + 5% Si oil solution is preferred because it contains a Si oil component that provides additional flexibility. If a return to an original color was preferred over strength, a solution containing a higher percentage of Si oil would be desirable, but the paper would become more slick and waxy to the touch and would tear more easily. The 95% MTMS + 5% Si oil solution was selected as the best treatment solution for the conservation of damaged paper.

Figure 24. The photo on the left shows the control weathered strips versus the 95% MTMS + 5% Si oil treated . The photo on the right shows the weathered control versus the treated weathered strips (from left to right).

Experiment 3. Accelerated Aging Experiment

One of the most often asked questions about any treatment used on paper is whether the treatment passed accelerated aging tests. Accelerating aging seeks to replicate the effects of aging on paper to determine if a treatment is successful, pointless, or damaging. Artificially aging paper is problematic. Some authors have stated that there is no correlation between natural and accelerated aging, and that the conclusions made from these data may not only be doubtful, but deceiving. (Bansa and Hofer 1989; Stroefer-Hua 1990; Bansa 1992).

Experiment 3 examined accelerated aging of control paper and paper treated with 95% MTMS and 5% Si oil. The hypothesis was that paper treated with 95% MTMS + 5% Si oil solution would withstand accelerated aging better than non-treated paper. Printer paper and Whatman #1 (100% cotton cellulose fiber paper) were used in the experiment. The printer paper used in this experiment, and all of the experiments where printer paper is listed as a part of an experiment, is Georgia-Pacific© "Everyday Copy and Print Paper," which has a 92 brightness, a 145 Whiteness (CIE-International Commission on Illumination standard), and 20 lb weight. It is 8.5" X 11" size and comes in 500 sheets per ream. It is regarded as being perfect for ordinary printing applications, acid free, and SFI® certified fiber sourced (Sustainable Forestry Initiative). Most likely, this paper is from the same production run.

The treated and control samples were placed into a scientific oven and heated to 90° Celsius for 15 days, emulating the equivalent of over 500 years of aging (Rance 1980a and 1980b). Figure 25 shows the alignment of the paper in the oven. Another group of treated and untreated samples, from the randomly selected book *Off on a Comet* (1952), were placed in the oven for 5 days. These pages are highly acidic and have yellowed as a result.

Figure 25. Paper submitted to accelerated aging in oven.

There was no discernable change between the control paper and the treated paper that was aged. Additionally, when the treated and control aged paper was compared to the control paper that was not submitted to accelerated aging, there was no change in color or composition. Since there was no change, it seems all of the experimental papers are more stable than previously believed. Accelerated aging is a controversial technique used to evaluate the endurance of paper or treatments. This experiment did not offer positive or negative results, but suggested that the test is not a valid measurement of aging in real-world conditions.

Experiment 4. Waterlogged Paper

As stated in Chapter IV, there are several recommended methods of conserving waterlogged paper. The most recommended for large quantities of paper and books is vacuum freeze drying, which removes the water from the paper by sublimation. The vacuum process is thought to facilitate the formation of smaller ice crystals that can be removed faster, causing less damage than conventional freezing, and so it was selected for the experiment.

Experiment 4 examined and compared methods of conserving waterlogged paper by air drying, freeze drying, and passivation polymers. Four groups of ten sheets of printer paper from the same production batch were stapled together and submerged for 48 hours in a single bath of tap water. Printer paper was selected, since it would have the fewest variables from sheet to sheet. The waterlogging conditions were selected to emulate what would happen in a situation of flooding from a burst pipe. There were no additional contaminates in the water.

After removal of the paper from the water, the samples were submitted to treatment. The air dried sample was laid on a clean tray and allowed to air dry over time (48 hours until totally dry). It was photographed and set aside to dry, as seen in Figure 26.

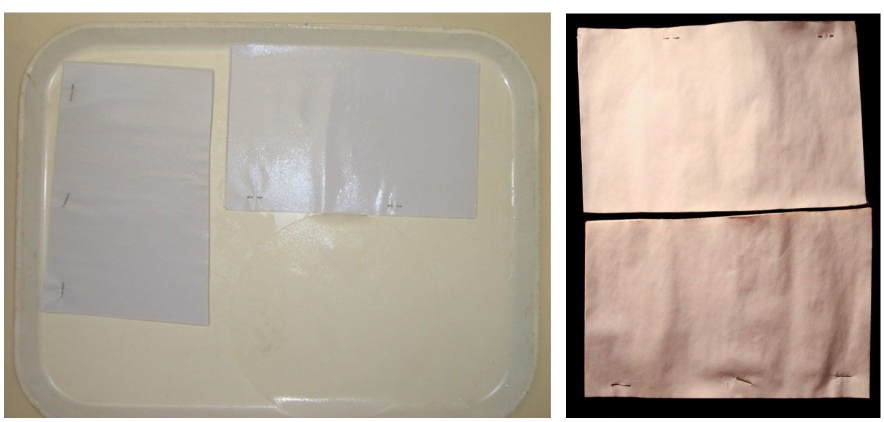


Figure 26. The air dried paper restrained by staples on one side. The before is on the left and the after is on the right.

The paper to be freeze dried was placed onto spun polyester sheeting, which was sewn into packets confining the paper. The vacuum freeze dryer and the packets of paper are shown in Figure 27. In a previous experiment, the paper to be freeze dried was not confined, and the weaker papers were blown to bits from the compression of the vacuum, which can be seen in Figure 28. This demonstrated that wet paper undergoes a great deal of stress as a result of vacuum freeze drying. Two different samples were submitted to vacuum freeze drying, which took which 32 hours to complete. When the

Figure 27. The vacuum freeze drier and the paper in polyester packets.

paper came out of the dryer, it was removed from the mesh bags. The paper was creased and cockled to some degree, shown in Figure 29.

After vacuum freeze drying the paper felt rougher, as if the fibers became loose, but this made the paper seem more soft and not as stiff to the touch when compared to the control. Neither sample was flattened. The first set of pages was analyzed and put

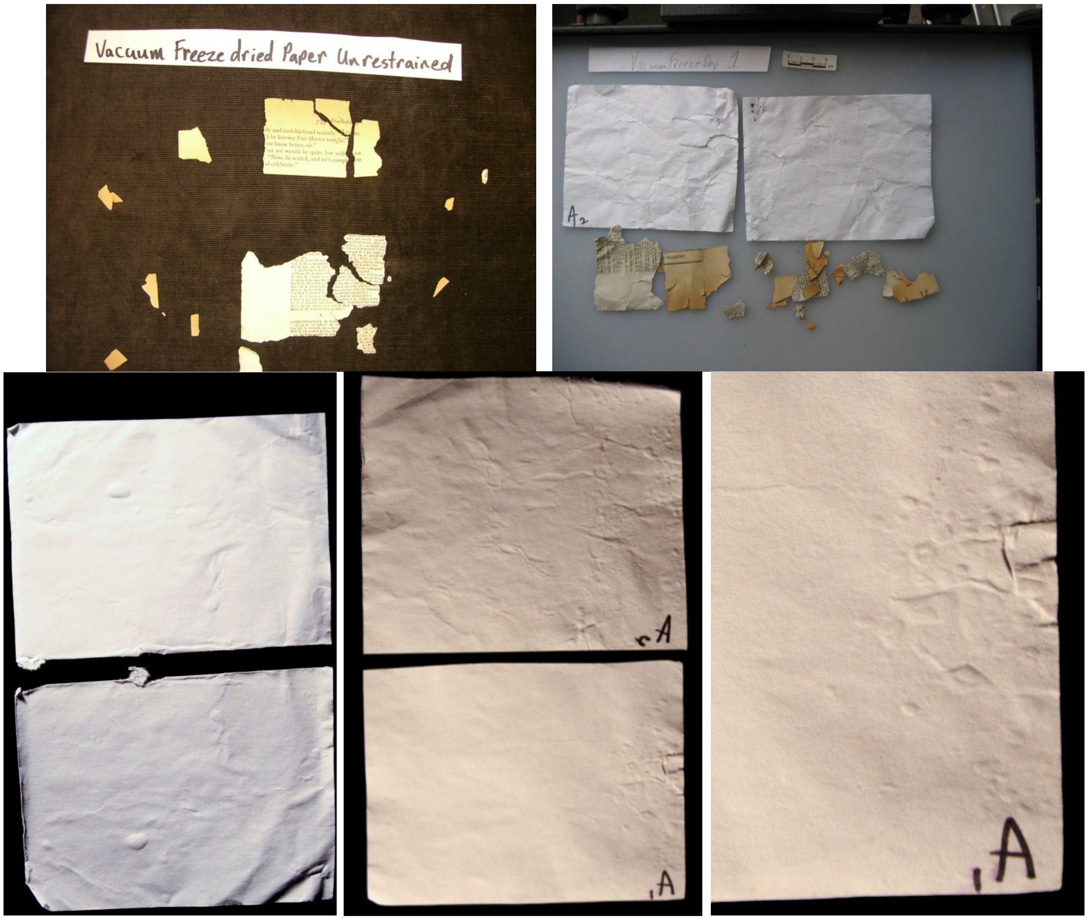


Figure 28. Unrestrained paper after vacuum freeze drying. Note the “bubbles” that have formed due to the uneven drying of the method.

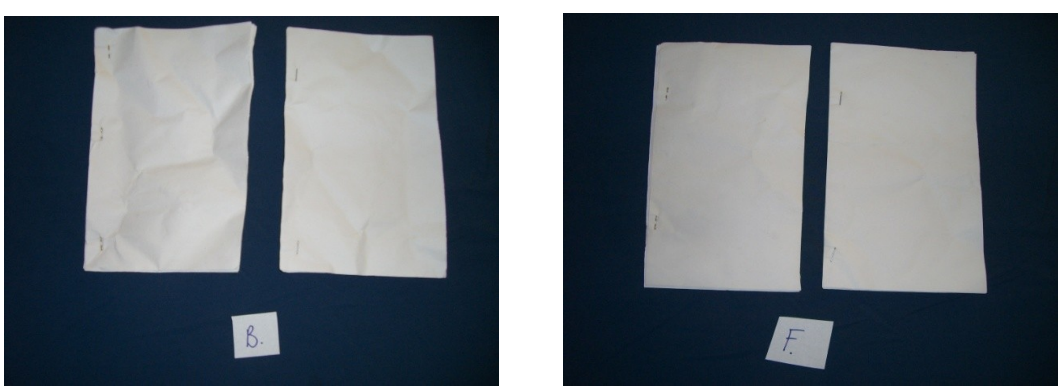


Figure 29. Post vacuum freeze dried paper (B.) and vacuum freeze dried paper after treatment with passivation polymers (F.).

aside. The second sample was put into a solution of 95% MTMS and 5% Si oil. After treatment, it did not feel as soft, and seemed more compact than the sheets in the first sample. Neither sample felt as compact or smooth as the control, but the treated sample felt more like the control than the untreated.

The waterlogged paper to be treated with passivation polymers needed to be dehydrated prior being placed into the solution. The baths began with a mixture of 25% ethanol and 75% water increasing in 25% increments to 100% ethanol. These were followed by baths of ethanol and acetone, beginning with 25% acetone and 75% ethanol increasing in 25% increments to 100% acetone. The paper went into a new bath every 20 minutes. It was then placed into a polymer solution of 95% MTMS and 5% Si oil (SDF 1) and left overnight.

Wet paper can be dried using organic solvent baths of increasing amounts, but it is not a usually recommended drying treatment, because solvents are difficult to dispose of and can cause ink to run. Several different solvents can be selected for dehydration, some of which may not affect the ink. After dehydration, the papers felt stiff, but that is to be expected. After polymer treatment, the paper felt very similar to the control. With the exception of a little warping, which is hard to see in Figure 30, and is probably the result of the relaxing of the fibers during the waterlogging, this method provided results that most closely resembled the control.

In order to better understand the effects of waterlogging paper, the ESEM photos in Figure 31 show what happens within the paper matrix. After waterlogging there is a loss of filler material and further stress on the fibers. They appear more broken and have

Figure 30. Paper after waterlogging and treatment with passivation polymers.

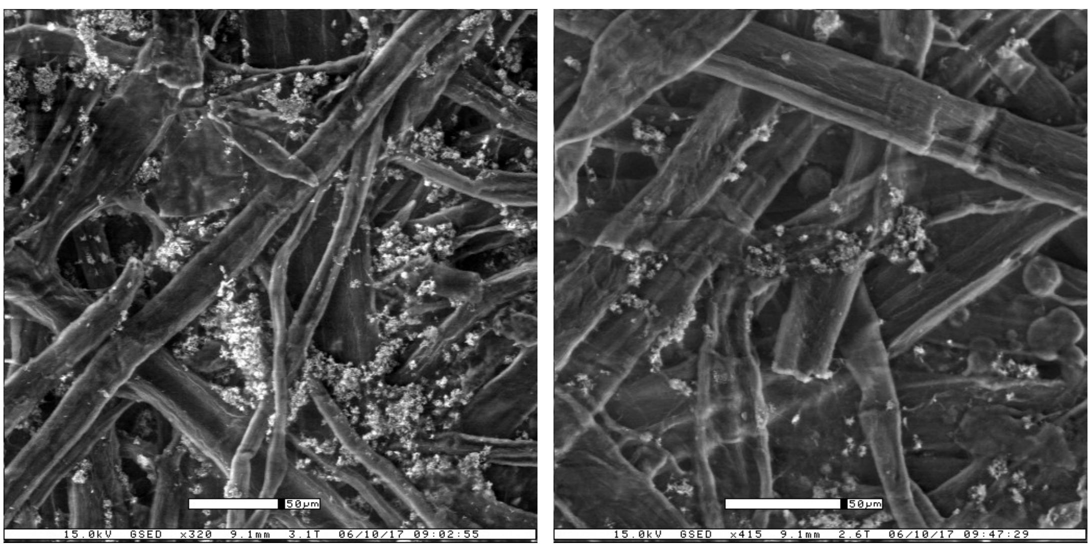


Figure 31. Printer paper control and printer paper after waterlogging ESEM photo (left to right).

hairs of fibrils detached from the individual fibers. The fibers look more compressed as well. The paper has lost fillers in the second photo, but the fibers look well-defined and strong.

Figure 32 shows ESEM photos of printer paper after treatment with solution and waterlogged printer paper that was dried and treated with passivation polymers (left to right). In the image of the printer paper after treatment, one can see the presence of the fillers within the matrix of the paper. It looks similar to the printer paper control seen in Figure 32. The treated waterlogged paper looks similar to the waterlogged paper in Figure 32 because of its loss of fillers, but the individual fibers in the treated sample of Figure 33 look smoother than the waterlogged untreated sample seen in Figure 32.

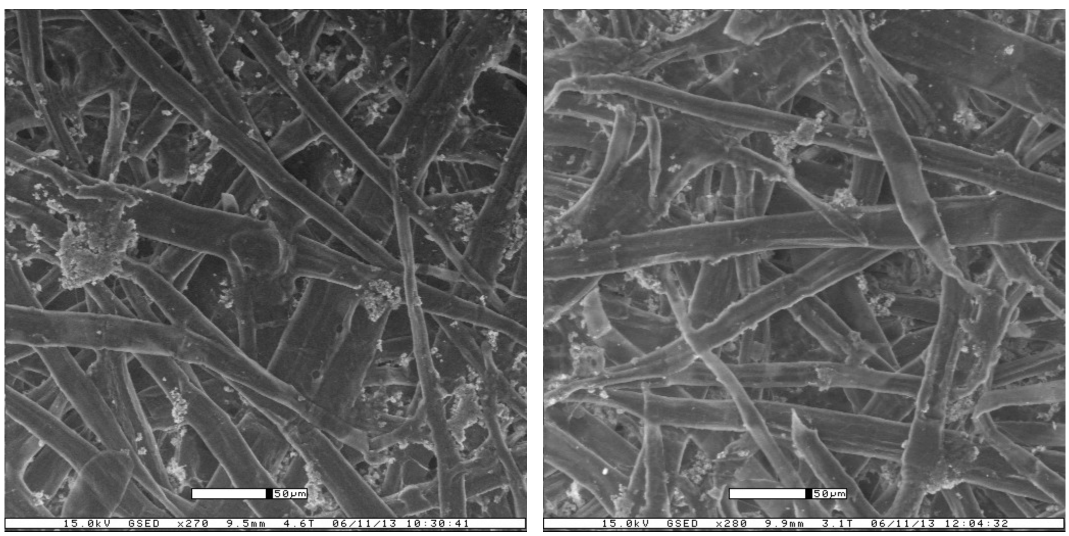


Figure 32. ESEM photos of printer paper after treatment with solution and right, waterlogged printer paper that was dried and treated with passivation polymers (left to right).

Figure 33 shows the effect of using 100% Si oil for the treatment of paper. These ESEM photos show how the matrix of the paper is difficult to see due to its saturation by the Si oil. The only difference between the two is the loss of fillers by the waterlogged sample. The fibers look smooth and strong, but the excess of oil renders the paper dark and weak. Perhaps this is a function of strengthening the interfiber bonds, but not forming a resin that strengthens the fiber to fiber bonds.

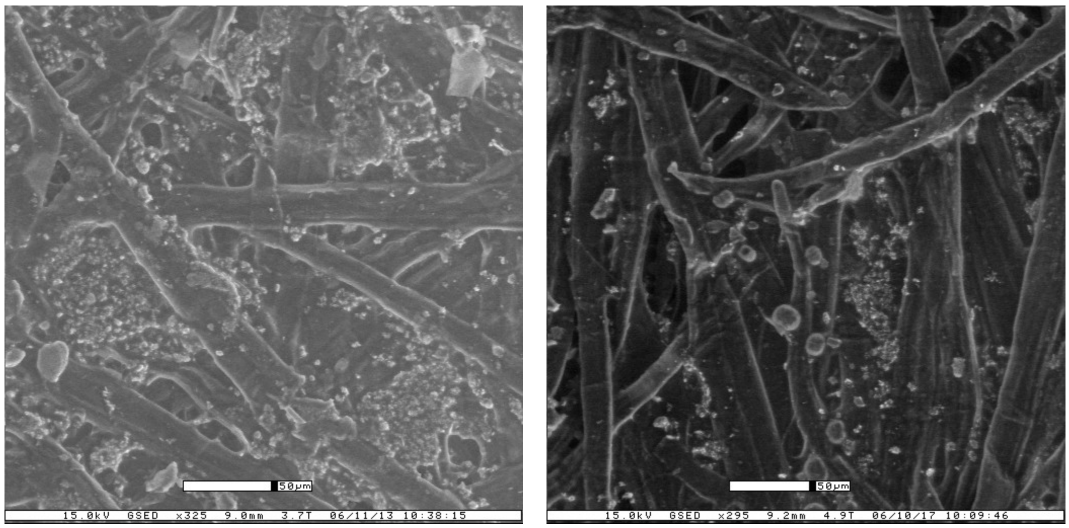


Figure 33. ESEM photo of printer paper after 100% Si oil treatment and waterlogged printer paper dried and treated with 100% Si Oil (left to right).

In conclusion, the appearance of the air dried sample was poor because it was warped and cockled, and it lost strength due to both the waterlogging and the unrestrained drying. The vacuum freeze dried paper feels softer and weaker than the control. After treatment with passivation polymers, the vacuum freeze dried paper did not feel as soft and was more compact, being more similar to the control. The wet paper that was submitted to organic solvent for drying and then placed into a passivation polymer solution, felt and responded very similar to the control. Since its features were more like the controls than either the air dried paper or the vacuum freeze dried paper, it provided the best treatment in the experiment examined here. While using organic solvents and passivation polymers provided the best result for individual pages of paper, if a disaster created a large quantity of waterlogged books, the best treatment would be vacuum freeze drying followed by Passivation Polymer treatment to regain the strength lost by the drying.

Experiment 5. Strength Testing

After the evaluation of the experimental printer papers in Experiment 4, the papers were sent to the Institute of Paper Science and Technology at the Georgia Institute of Technology to be tested. All of the paper samples sent were from the same batch of printer paper, as stated in Experiment 3, to limit the number of possible variables and to try to remain consistent in sampling. A control and a plain paper that was treated with passivation polymers were analyzed, in addition to the air dried sample, the vacuum freeze dried sample, the vacuum freeze dried treated sample, and the dehydrated treated sample created in Experiment 4.

After consulting with Dr. Roman Popil, Senior Research Scientist at the Institute of Paper Science and Technology, it was decided that ultrasonic instrument measurement and the MIT fold test could possibly provide more relevant data compared to other possible tests. The ultrasonic tests are new technology, used to measure specifications for industry. They were completed using Sonisys OPUS 3-D and L&W TSO instruments. Ultrasonic instruments measure the propagation of sound directionally through (out of plane) or along (in-plane) of a sheet. The directional speed of sound squared is divided by the density of the material, and that number is directly related to the elastic constants of the paper pertaining to the mode and direction of sound propagation. In the cases tested, the sound waves may be longitudinal waves or shear waves, depending on the selected situation. The tests determine the cross-direction (CD), the machine direction (MD), and the thickness of the sheet (ZD) moduli. The higher the numbers received by the test, the better the quality of the paper is thought to be.

The MIT Fold Test tests strips 15 mm wide and 160 mm long cut along the machine direction, which are suspended under tension as applied by a one kilogram weight tensioning spring. The number of cycles of the rocking anvil required to break the paper are recorded as a measure of the folding resistance. A comparison of significant differences between samples can be made through comparison of the results with error bars representing the 95% confidence intervals of the results from repeated measurements for each sample.

As stated before, the testing of paper to derive specifics about its quality and durability is incredibly complex. There are many different variables that need to be considered when evaluating any results. The tests used to evaluate paper are created to evaluate industrially made paper that is tested soon after it is made, eliminating any changes that might have resulted from its aging or storage. The tests are run hundreds or thousands of times to better measure the effects or changes that the paper may have undergone. They may not provide a good measure of aged or damaged paper.

Because of the expense of the testing, each paper type submitted for testing to the Institute was tested only ten times per type: a statistically small sample. The waterlogging of the paper adds other variables that can affect the results. The handling of the paper by the researcher or the mail service could have altered the paper prior to testing, as well as many other factors. Additionally, Dr. Popil stated that the machines had to be tweaked (his word) to measure the texture of the damaged paper. One cannot be sure what effect tweaking had upon the results, but the tester seemed confident that it brought the machine to correct measurements. The full report provided by the lab is in the appendix.

These tests provided interesting results, yet the data may not provide definitive proof that one paper is stronger than another. The data from the Sonisys OPUS 3-D ultrasonic measurements and MIT folds can be seen in Table 2. The MIT Fold test

Table 2. Summary of Sonisys OPUS 3-D ultrasonic measurements and MIT folds. The stiffnesses have been converted by Poisson ratio measurement of calculations, caliper, and basis weight.

Sample ID	Paper type	Basis weight	Caliper	Density	ZD modulus	c.i.
		g/m^2	microns	kg/m^3	MPa	
A.	Air dried after Waterlogging	75.7	103.8	729	323.5	20.5
B.	Vacuum Freeze Dried	76.5	124.4	617.9	72.5	32.4
C.	Control	76.5	98.4	780.4	268.2	34.2
D.	Treated Control	79.9	99.2	806	296.1	5.5
E.	Waterlogged Treated	85.4	118.8	718.7	147.5	14.4
F.	Vacuum Treated	79.2	130.3	608.4	26.7	23

Sample ID	MD Modulus		CD Modulus		MIT folds		
	GPa	c.i.	GPa	c.i.		c.i.	
A.	7.077	0.328	2.95	0.149	122.6	36.0	58.1
B.	3.7	0.427	1.1292	0.148	19.6	6.9	11.2
C.	8.171	0.522	3.327	0.133	104.5	35.9	58
D.	7.951	0.129	3.302	0.129	62.7	11.1	17.9
E.	5.289	0.211	1.92	0.047	5.3	0.4	0.7
F.	3.684	0.291	1.374	0.092	15.1	4.0	6.5

returned unexpected results. Figure 34 shows the results of the MIT Fold test. The fold test is questionable, and as stated by other authors, it may not measure any change in the paper or provide a false negative. When this test was suggested to Dr. Popil, he was skeptical that it would provide useful data, due to the high level of statistical error, but since it was used to test the strength of paper in the literature it was selected as well.

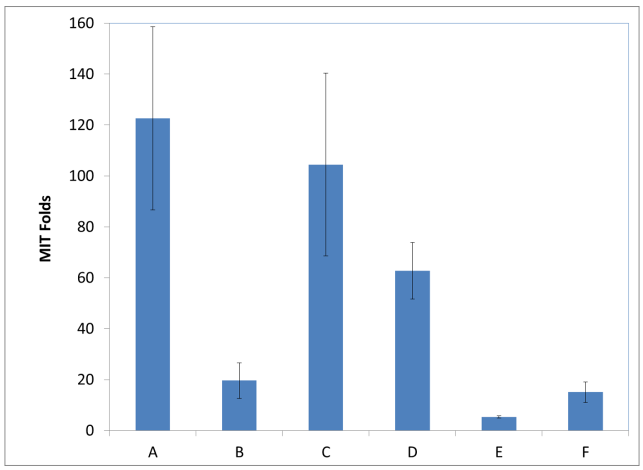


Figure 34. MIT folds. The behavior appears to qualitatively follow the elastic moduli: the more elastic, the more folds and the stiffer, the fewer folds.

The results of the MIT Fold Test showed that the air dried sample (A) returned the highest number of folds, even beating out the control (C) that was assumed to provide the best result, yet came in second to the air dried sample. The treated control (D) was third, followed by the vacuum freeze dried sample (B) and the treated vacuum freeze dried sample (F). Both of the freeze dried samples tested evenly, within each's margin of error. The waterlogged treated sample (E) returned the worst results. There are several explanations of these results. It is possible that test was incorrectly performed. Most likely, this is not the cause, but the average of the small number of repetitions could be a factor. The air dried sample would have been the most flexible due to its exposure it to water, causing the relaxing and a realignment of the fibers, without the dried in stressors from manufacturing. This does not mean that the paper would have been made stronger; rather, it became better at bending. The treated control did not fold as many times as the control, which was expected, since the treatment makes the paper stronger by reinforcing the matrix of the fibers. This causes a stiffening of the sheet, which could affect the folding. It was expected that the treated vacuum freeze dried samples would have returned results better than the untreated vacuum freeze dried samples, but since the solution makes the matrix stronger, it explains the slightly less favorable result that the treated paper received. Still, both vacuum freeze dried samples returned a statistically similar result. The dehydrated and treated sample returned the fewest number of folds because it would have had the stiffest sheets, from both the realignment of the fibers during dehydration and the added stiffness of the strengthening of the fiber network.

The ultrasonic measurement tests provided different data, but the results may be flawed as well and may not indicate the strength or permanence of the paper. The ultrasonic measurement is based upon the density of the paper, which can vary because of production processes, the waterlogging, and the conservation treatment. For instance, the treated control had the highest density.

The Sonisys OPUS 3-D ultrasound returned more expected results than the fold test, which could be seen in the data table of Table 2 and in the bar graph of Figure 35. The control provided the best result, and the treated control had the second best score, which were the expected results. The air dried sample unexpectedly scored well with the third best results. The dehydrated and treated sample tested better than either of the vacuum freeze dried samples, and returned the fourth best results. The vacuum freeze dried samples had scores within the same margin of error in the MD, but the treated vacuum freeze dried sample returned slightly better results in the CD, while the untreated had a much better score in the ZD. The paper was equally damaged by the vacuum freeze drier, but the difference in the ZD score can be explained as a result of the strengthening of the fiber matrix, which would have flattened the fibers in the Z direction. The vacuum freeze dried paper did require the tweaking of the data collection, which may have affected the results.

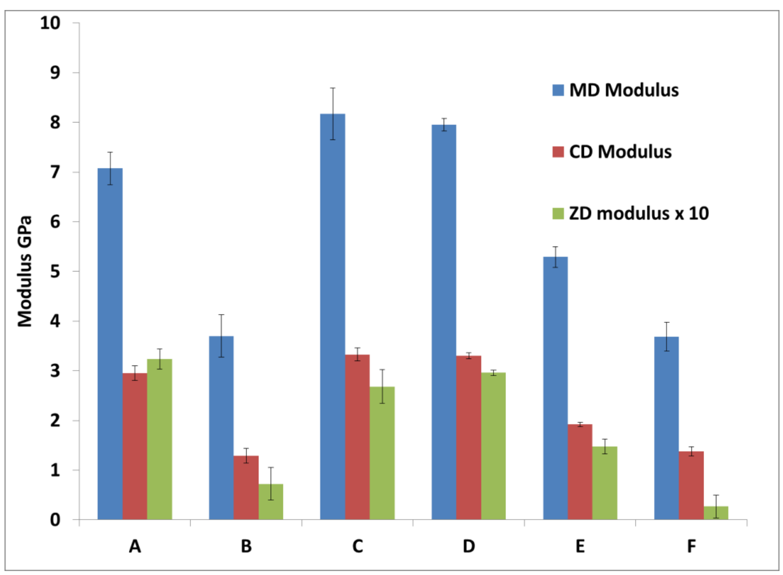


Figure 35. Summary of the in-plane (MD and CD) and out of plane (ZD) elastic moduli from the Sonisys OPUS 3-D ultrasound. Higher values are thought indicate a better quality of sheet when testing for industrial specifications. Note the ZD modulus in the figure has its values multiplied by 10 in order to fit on the same scale.

The L&W TSO ultrasound returned results similar to the first two tests that are shown in Table 3 and Figure 36. The unexpected result, similar to the results from the fold test, was that the air dried sample returned strong results, posting the best numbers

Table 3. The L&W TSO in-plane ultrasonic measurements. The in-plane moduli were calculated by dividing the TSI values by the density of the respective sample.

SAMPLE ID	TSI_MD		TSI_CD		TSI MS mod	TSI CD mod
A	8.63	0.06	3.82	0.04	11.84	5.24
B	4.69	0.07	1.94	0.33	7.59	3.14
C	9.19	0.24	3.96	0.22	11.78	5.07
D	8.92	0.15	3.84	0.16	11.07	4.76
E	6.36	0.39	2.34	0.2	8.85	3.26
F	5.22	0.46	2.21	0.2	8.58	3.63

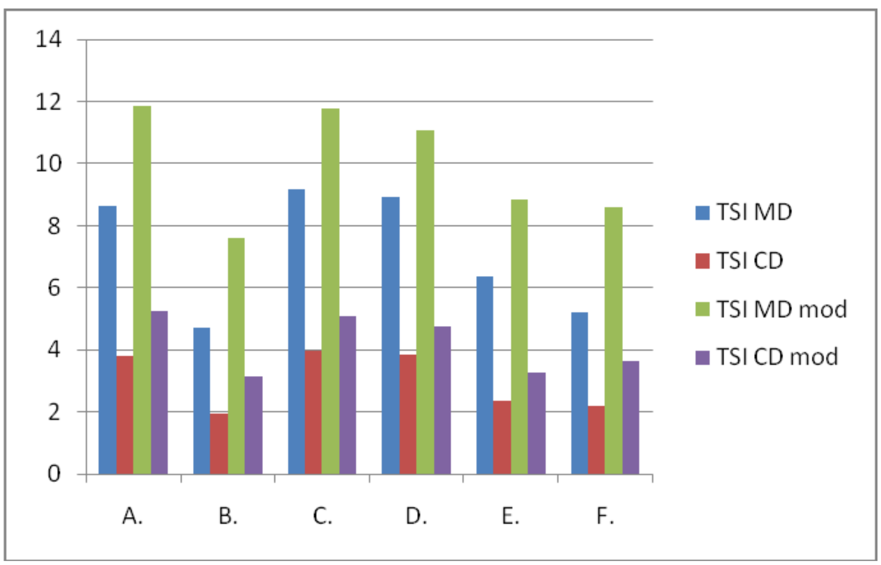


Figure 36. L&W TSO ultrasound results.

in the MS and CD moduli. These results can be explained by the lighter density of the paper caused by the relaxing of the fibers and unrestrained drying. Since the density was smaller, when the MD and CD were divided by each samples density, the moduli was larger. Without the moduli equation, the control provided the best result with the treated control providing the second best result. The dehydrated and treated sample provided the fourth best results. The treated vacuum freeze dried samples returned results better than those of the untreated, but they had the lowest overall scores. According to this test, the treated vacuum freeze dried paper has a higher rating than the untreated vacuum freeze dried paper.

The results from these tests do not definitively state which of the papers is stronger than another or which has the highest quality. In fact, none of these tests measure the strength of the paper. The fold test measures the elasticity of the paper matrix, and the ultrasonic tests examine the density scores of sound waves penetrating paper. These were the tests suggested by Dr. Popil, but even he was skeptical that they would successfully demonstrate an increase of strength or permanence as a result of the polymer treatment. It was informative to examine the data derived from these tests, but the Institute may have been testing properties that have no relevance in determining the strength of the waterlogged paper or the effect of any of the experimental treatments. These tests were included for two reasons. The first was to demonstrate that the attempt was made to compare the industry standards to the effects of the polymer solution on damaged paper. The second was to show that it is not possible to relate damaged paper and its conservation to the standards set by industry in determining the quality of conserved paper.

Experiment 6. Mold

As stated in the previous section on mold and its removal, the best method for the eradication of mold is to irradiate it. Unlike the chemical methods of mold eradication, which are toxic and leave dangerous residues behind, radiation kills mold and does not leave any harmful residue. The only issue with radiation as a treatment is that it weakens the paper significantly. The weak paper can be made stable, stronger, and more flexible by the polymer treatment.

It has been suggested that the polymer solution has fungistatic (mold resistant) properties. In order to test this hypothesis, Experiment 4 was designed. Control printer paper discs and treated printer paper discs were prepared. Both were from the same batch of paper. These were placed onto opposite sides of a sterile starch agar Petri plate. To insure that mold that infects paper would be present, small sections of two different moldy papers were placed onto each plate. In previous experiments, if the mold was not introduced, other fungi and bacteria were evident on the plate. Figure 37 is an example of a plate before incubation.

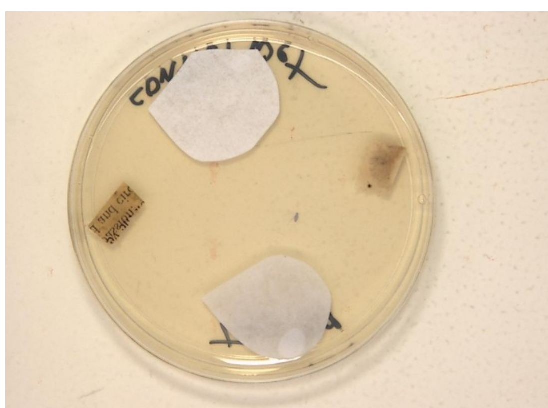


Figure 37. A plate before incubation. The plates were labeled on the bottom.

The prepared plates were placed into an 80°F incubator for three days, and then they were removed, analyzed, and photographed. There was mold growing outward from the infected paper, but it was not growing on either the control or the treated paper. There seems to be some activity on the control paper, but more time was necessary for additional growth, which can be seen in Figure 38.

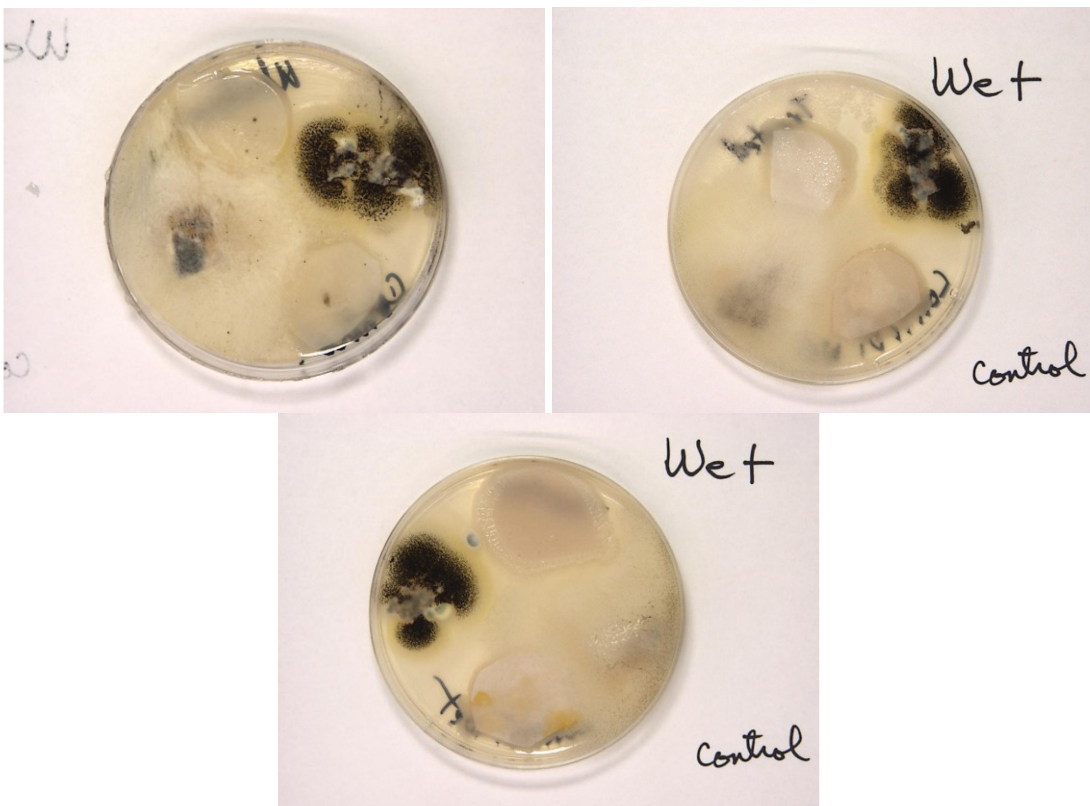


Figure 38. Plates after three days. The “wet” side is the treated paper and the control is on the opposite side.

After an additional four days (seven days total) of incubation, there was mold growing on the control paper, while the treated paper resisted mold growth, exhibiting fungistatic properties. Figure 39 shows the mold growing on the control papers, but not on the treated. The plate seen on the bottom appears to be growing a black mold on the periphery, but this is just the mycelia of the colony on the plate overlapping the edge of the treated paper.

The fungistatic properties of passivation polymers provide another reason to use the polymer treatment on severely damaged paper. Damaged paper is especially at risk to incur additional damage. Paper that has already been waterlogged or damaged by

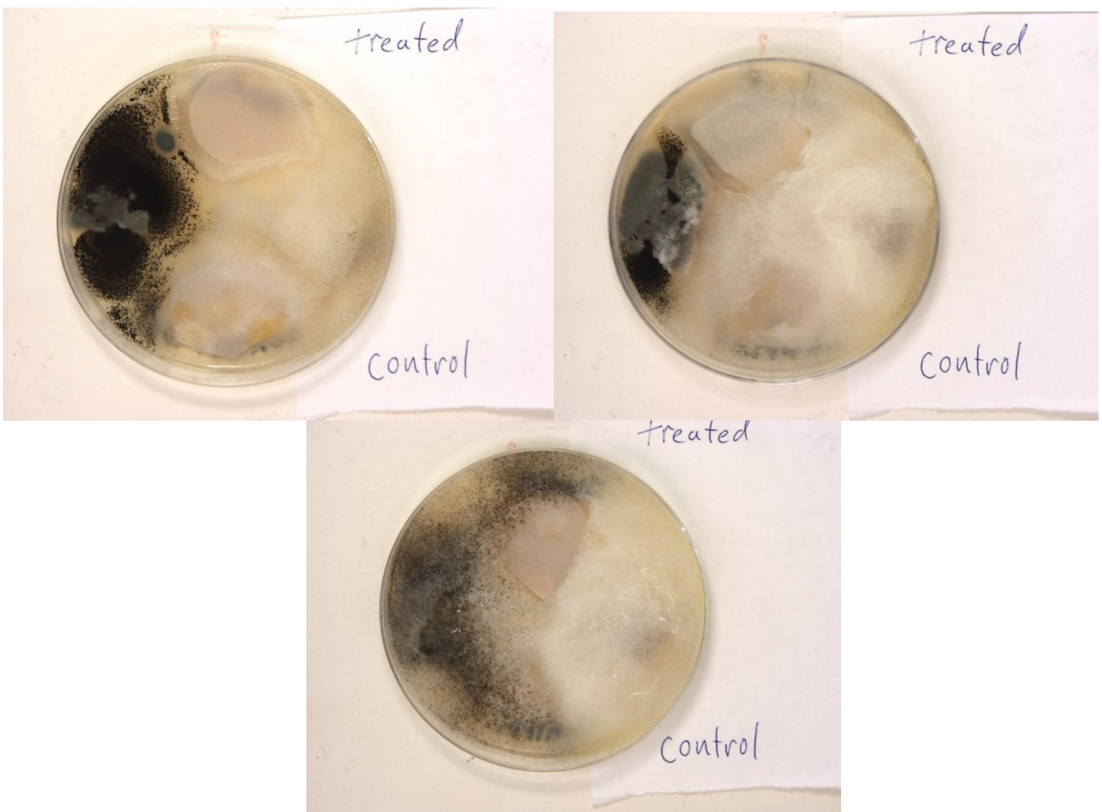


Figure 39. Plates after seven days. On the top two plates, no mold can be seen on the treated plates, demonstrating fungistatic properties. On the third, bottom plate, it looks like the black mold has begun to grow on the periphery, but this is just the mycelium from the plate growing around it, rather than on it. The control is growing its own colonies.

mold and radiation would be a greater risk for infection by mold. The fungistatic properties of the polymer treatment would provide protection against further infection by mold. Conserving paper with passivation polymers can provide additional attributes beyond strength and stability, such as resistance to mold infestation.

Experiment 7. Deacidification

As discussed in Chapter IV, another of the major problems of deteriorating paper is internal acidity. Treatments to deacidify are controversial and varied. While it is assumed that a high level of acid compounds and a low pH in paper signify a weakened paper, Hendriks, in his article "Permanence of Paper in Light of Six Centuries of Papermaking in Europe," stated that the acidity of paper is not necessarily indicative of the state of permanence of paper (Hendriks 1994). Papers with a high level of acid may survive over time, but they are more susceptible to other damaging agents as a result and must be handled very carefully.

The goal of any deacidification treatment is to increase the strength of the paper by raising the pH of the paper through the neutralization of acids and the impregnation of buffer material. Many different buffers are suggested, but calcium carbonate is the standard for the Library of Congress (2004). Some of the buffers suggested in the literature can raise the pH excessively high, causing different problems to arise. While many of the treatments suggested are viable, there are inherent problems with those methods. Furthermore, they do not provide additional strength or stability to the paper.

Experiment 7 was conducted to determine if passivation polymers could be used as a deacidification treatment or as a part of a deacidification protocol. Two acidic papers from books were selected: *Concordance*, printed in 1812, and *Off on a Comet*, printed in 1952. Printer paper and Whatman #1 filter paper were tested as well, after the initial results were obtained from the two acidic papers. Controls of each paper were set aside. Five different treatments were selected. The first treatment involved washing the papers in distilled water (pH 7 neutral) with $CaCO_3$ dissolved in the water. This is a traditionally accepted method of washing out the loose acid and depositing a buffer material within the paper. The paper went through six baths of 20 minute increments, and was dried by pressing between blotters repeatedly. The second treatment involved brushing dry $CaCO_3$ onto dry paper, brushing off the loose buffer, and then spraying 95% MTMS + 5% Si oil onto the paper. In the third treatment, a solution of 95% MTMS + 5% Si oil and $CaCO_3$ mixed together was sprayed onto the paper. The fourth treatment placed pages that had been washed using the first treatment into a solution of 95% MTMS + 5% Si oil. The fifth treatment sprayed a solution of 95% MTMS + 5% Si oil onto the paper with no additional buffer present.

Each paper was submitted to the TAPPI T509 cold water extraction test to measure the pH. Two different litmus papers, made by Baker and EMD, were used to determine the pH. The chart below lists the results of the average pH after multiple tests.

The results were excellent, and can be seen in Table 4. The controls of the both of the book papers were found to be acidic. The first treatment, washing in the

Table 4. pH measurements.

Paper	Baker Litmus	EMD Litmus
$CaCO_3$ solution in DI water no paper or treatment	pH 8	pH 7.5
Off on a Comet untreated control	pH 4.5 limit of paper	pH 3
Off on a Comet washed with DI water and $CaCO_3$	pH 6.75	pH 6.5
Off on a Comet washed with DI water and $CaCO_3$ and dipped into MTMS solution	pH 6.75	pH 6.5
Off on a Comet Dusted with $CaCO_3$ and later sprayed with MTMS solution	pH 6.5	pH 6.5
Off on a Comet Sprayed with CaCo3 + Solution	pH 7.3	pH 6.9
Off on a Comet in 95% MTMS + 5% Si oil solution	pH 4.5	pH 4

Concordance untreated control	pH 4.5 limit of paper	pH 4
Concordance washed with DI water and $CaCO_3$	pH 7	pH 6.5
Concordance washed with DI water and $CaCO_3$ and dipped into solution	pH 7	pH 6.5
Concordance Dusted with $CaCO_3$ and later sprayed with solution	pH 7	pH 7
Concordance Sprayed with CaCo3 + Solution	pH 7.5	pH 6.5
Concordance sprayed with solution	pH 4.5 limit of paper	pH 4

Whatman # 1 control	pH 6.5	pH 6.5
Whatman #1 dusted with $CaCO_3$ and sprayed	pH 7.5	pH 6.5
Whatman #1 sprayed with solution and $CaCO_3$	pH 7.5	pH 6.5
Printer paper control	pH 8	pH 8
Printer paper sprayed with Sprayed with CaCo3 + Solution	pH 8	pH 8

traditional method, showed expected results. The paper became less acidic, but only the treated *Concordance* paper met the Library of Congress' standard by raising the pH into the acceptable range between 6.8 and 10.4 pH. The process was time and labor consuming, and the use of expensive distilled water and blotter paper causes this treatment to be the most expensive.

The second test, dusting with $CaCO_3$ and spraying with the polymer solution, returned favorable results. This two-step process did lower the pH appreciably, and a buffer was placed onto the paper. The *Comet* paper did not respond as well as the *Concordance* paper, since the Baker litmus indicated that the washed paper had a higher pH than the dusted paper. The *Concordance* paper performed better than the washed paper using this treatment.

The third test provided the most favorable results. The pH was raised in both book papers and it implanted a neutralizing buffer into the paper. Initially, the paper had a grainy feel. This is the result of too much buffering agent applied to the paper during the application, and was easily removed by a soft brush. It felt the same as the control afterwards. Since this process returned the most favorable results, and provided the easiest application of the treatment, it was deemed the best deacidification of the tested processes.

The fourth test, which placed the washed paper into the polymer solution, returned expected results. Because the pH did not change, it can be assumed that the polymer solution does not affect the pH as it is registered by litmus paper. The only difference is the addition of strength by the polymer treatment. The fifth test of placing the paper directly into the polymer solution reinforced these results because the treatment did nothing to improve the pH.

After the book papers were tested, printer paper and Whatman#1 filter paper were selected to test the most successful treatments. The printer paper did not change in its pH. It was already buffered before the test, which can be seen in its ESEM photo in Figure 40.

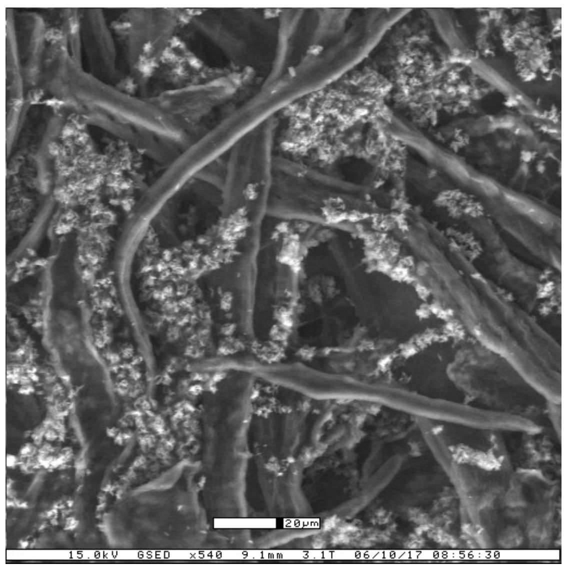


Figure 40. ESEM photo of printer paper.

The Whatman #1 paper improved significantly by increasing its pH from acidic to basic. When Whatman paper it is newly produced, it is assumed to be pH neutral, because it is 100% cotton linter based, so it can be used as filter paper without imparting any effect in an experiment. This paper was recently acquired from the Texas A&M University chemical stores, and can be assumed to be recently made.

An unintended consequence of these experiments led to an interesting discovery. During the extraction tests, one gram of paper, cut into small squares, was placed into a beaker with 70 ml of water, and agitated for one hour using a magnetic stirrer. After the pH was measured, two beakers were left overnight containing printer paper in water and 95% MTMS + 5% Si oil treated printer paper in water with no additional agitation. The next day, it was observed that the untreated printer paper turned into a slurry of indefinable, loose paper squares. The edges of each paper square looked ragged and loose. The treated printer paper looked the same as when it went into the water: the edges still crisp as when originally cut. The cut-up untreated printer paper was reproduced in five beakers and allowed to sit another night. All had the same appearance of a loose slurry with undefined edges on each paper square. After 48 hours, the treated paper appeared the same, while the first batch of untreated printer paper was even more dissolved. The experimental paper can be seen in Figure 41 and Figure 42.

Figure 41. The beakers, viewed from the side from left to right are: 48 hour old untreated printer paper, 24 hour old untreated printer paper, and 48 hour old treated paper.

The untreated printer paper suffered from both the relaxing of the fiber matrix and a breaking of the bonds within the cellulose due to the presence of water and its initial agitation. The fillers and buffers from within the paper were released into the water causing it to become translucent. The treated paper maintained its original ordered

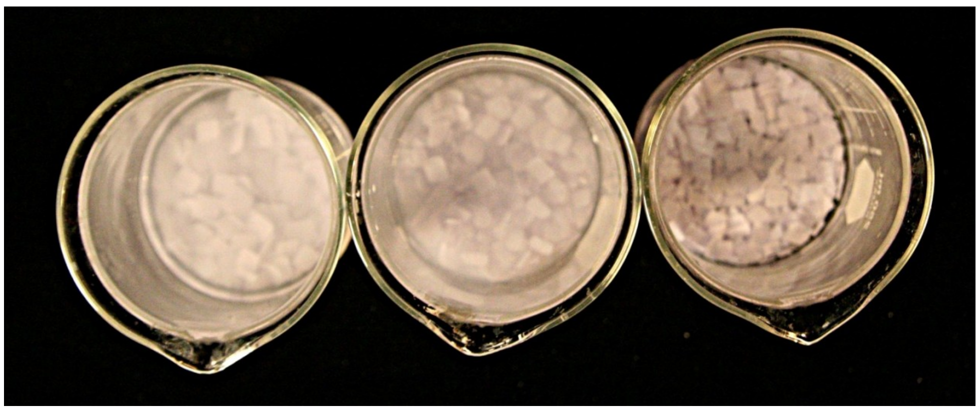


Figure 42. The beakers, from the top and from left to right are: 48 hour old untreated printer paper, 24 hour old untreated printer paper, and 48 hour old treated paper. Observe the translucent quality of the water in the untreated paper, while it is possible to see the bottom of the glass in the treated paper.

alignment, which is due to the polymer network that supports the cellulose matrix of the paper. The fibers of the treated paper may have absorbed some water, but not enough to cause the expansion of the matrix, as seen in the untreated paper. The fillers and buffers present within the paper have not been released from the matrix. The treated paper has more wet strength than the untreated. Passivation Polymer treatment provides additional strength to paper, even when it is wet.

In conclusion, the pH tests of the book paper controls confirmed the presence of acid within the paper. When the paper was washed using a conventional treatment protocol, the acids are removed or stabilized. However, washing is labor and time intensive, and renders the paper weak. Treating the washed paper with MTMS solution did not change the pH, but it made the paper stronger. The best treatment, as determined by these experiments, is the $CaCO_3$ in a 95% MTMS + 5% Si oil solution sprayed on to the surface of the paper and brushed with a soft brush. The treatment raised the pH, did not affect the feel or texture, generally did not affect its appearance, and deposited an alkali buffer into the paper. The stability of the paper was increased as a result of the polymer's reaction to the carbonols created during hydrolysis and oxidation.

The unintended discovery of the maintenance of the shape of the individual pieces of paper of the treated printer paper in water shows that the paper is made stronger and retains more of its original characteristics as a result of treatment. This demonstrates that the solution strengthens the paper so significantly that even when wet, the fibers in the treated printer paper did not relax enough to become loosened in the water. The fibers in the untreated printer paper relaxed significantly due to the absorption of water over time, which caused the breaking of both the fiber-to-fiber bonds and the interfiber bonds within the cellulose fibrils.

Conclusion

As a result of these experiments, Passivation Polymer treatment has demonstrated that it is an effective protocol to conserve severely damaged paper. The first two experiments provided the formula for the best solution of the polymers. The third experiment attempted to evaluate the effects of accelerated aging on treated and untreated papers. Interestingly, no effect was seen on any of the papers after the aging, rendering this experiment evenly balanced, but uninformative.

The fourth experiment, the treatment of waterlogged paper, was successful in its results. It demonstrated that bound waterlogged paper could be effectively conserved using several different protocols, all using passivation polymers as part of the treatment. Air drying is effective, if the only goal is dry paper, but the paper became distorted as a result. The wet paper that was sent through a series of dehydration baths and treated with passivation polymers looked and felt the best. It is assumed to be the strongest of the group. The vacuum freeze dried samples became soft and distorted as a result of the formation of water crystals within the matrix of the paper. The vacuum freeze dried treated sample felt more smooth and stronger after polymer treatment. This protocol would provide the best results for a large volume of waterlogged bound material.

The fifth experiment, the submission of papers for industrial testing, presented interesting data. It is not certain whether these tests provided data that can be applied to measuring the effectiveness of using passivation polymers as a conservation treatment. Even the Senior Researcher, Dr. Popil, was unsure if the tests would provide useful data. Most of the results were predictable, but the results for the air dried paper were not. In hindsight, the outcome can be justified, but it was assumed that the control would have the best result in every test. It was thought that the treated vacuum freeze dried paper would have tested much better than the weakened vacuum freeze dried paper, but none of the tests tested the increase of strength between the two, so in hindsight, the results are logical.

The sixth experiment tested the fungistatic qualities of the treated paper. It had been thought that passivation polymers made treated artifacts resistant to mold. The experiment demonstrated that the polymer treatment does make paper resistant to a mold infestation, which enhances its use as an effective conservation treatment. Not only does it improve so many other qualities of the paper, but it can actively resist the molds that are present everywhere.

The seventh experiment, deacidification, demonstrated that passivation polymers in combination with an alkali buffer can be used as an effective deacidification agent. It is thought that passivation polymers stabilize the chemical structure of the cellulose, and strengthen the interfiber network by creating a supporting system in the matrix of the paper. With the addition of an alkali buffer into the polymer solution, the pH is raised to an acceptable level and the paper is made stronger, even reversing some of the effects from the deterioration from the acidic compounds.

All of these experiments have demonstrated that passivation polymers are a major asset in the treatment of severely damaged paper. By using the polymer solution as a part of a conservation treatment protocol, paper can be treated to raise the pH, prevent mold, and preserve waterlogged paper. The strength and stability that the polymer solution imparts to damaged paper makes treatment with passivation polymers an invaluable conservation technique.

CHAPTER VII

CONSERVATION OF PAPER ARTIFACTS FROM THE BONFIRE MEMORABILIA COLLECTION

This chapter establishes the effectiveness of passivation polymers as a conservation treatment. Selected paper artifacts from the spontaneous shrines erected at Texas A&M University after the collapse of the Bonfire in 1999 were conserved using this protocol. These artifacts became damaged as a result of being left outside in the Texas fall for a month. They have issues of mold, exposure, debris, and repeated episodes of waterlogging and drying, and because of their compromised state, they are perfect candidates for conservation using passivation polymers.

A fairly recent phenomenon in the United States and elsewhere is the construction of spontaneous shrines at sites of tragedy or other places that are associated with the individuals who have died violent deaths. Shrines have become a way for the public to mourn those who have suffered a sudden or shocking death, who may not have been known to them personally, but none-the-less, feel a sense of loss from their passing. The wall outside the Oklahoma Murrah Federal Building, Ground Zero in New York City, Texas A&M University, the places associated with Princess Diana, the Columbine High School, Virginia Tech University, Northern Illinois University, and others in the past all became powerful scenes of demonstration of an outpouring of grief by the erection of spontaneous shrines. Because of their relatively new cultural status and the power of the group identity exhibited in their constructions, spontaneous shrines are being researched by scholars in various disciplines, in order to understand this new cultural movement and the artifacts left behind.

Spontaneous shrines are best defined by the standards of the scholars employed in their understanding. Grider, in her 2005 work, “Vernacular Memorialization of School Tragedies: A Chronological Study,” concisely defines shrines by stating, “Spontaneous shrines are basically communally-created material culture assemblages at or near the actual place of violent death,” (Grider 2005: 80). Jack Santino, a folklorist and editor of several works on spontaneous shrines, including *Performative Commemoratives: Spontaneous Shrines and the Public Memorialization of Death* (2006a and 2006b) states that “The spontaneous shrine is a genre of mourning ritual. Spontaneous shrines have emerged, both in the United States and internationally, as a primary way to mourn those who have died a sudden or shocking death, and to acknowledge the circumstances of the deaths” (Santino 2006b: 5). Haney et al., in their 1997 article “Spontaneous Memorialization: Violent Death and Emerging Mourning Ritual,” state, that shrines are “a public response to the unanticipated violent deaths of people who do not fit into the categories of those we expect to die, who may be engaging in routine activities in which there is a reasonable expectation of safety, and with whom the participants in the ritual share some common identification” (Haney et al. 1997:161). The public is not prepared to deal with unanticipated, violent deaths of people not normally expected to die, both because of their age and because they were conducting normal “safe” routine activities, like going to work or returning from dinner. One of the ways that people seem to deal with these tragedies is by visiting, viewing, and contributing to these shrines. This emerging American mourning ritual offers the chance to mourn individuals unconventionally in a way not included in traditional rites, while also calling attention the social and cultural risks associated with the occasion of these deaths (Haney et al. 1997).

Journalists have called these shrines "makeshift memorials," but they are not makeshift. These are places that people linger, visit, and sometimes sit for hours in contemplation. The places have a rhythm, a precision, and aesthetic arrangement, and a behavioral set all of their own (Yocom 2006). "Spontaneous shrine" is a more appropriate term for these memorials as they function as sites of ritual pilgrimage and they emerge very quickly, often within the first few hours after the event. They are not makeshift, as they are folk art assemblages with a coherent organizational principle in the arraignment of the material, resulting in an aesthetically pleasing appearance (Grider 2001).

Spontaneous shrines have become the commonplace when tragedy strikes; not only appropriate, but expected (Grider 2001). They are places where individuals or groups have chosen to leave items and memorabilia in remembrance of those who have perished, and are erected spontaneously at sites of tragedy. Spontaneous shrines occur at the site of the death or another area closely associated with the deceased, rather than at a prescribed place of mourning (Haney et al. 1997). Shrines usually develop as close to the site of the disaster as possible, and where ever the initial artifact(s) was placed, more and more artifacts quickly accumulate (Grider 2001). The objects that exist at the site often become magnets for shrines, like structures surrounding the site or other items, like signage (Haney et al. 1997). At Texas A&M University, within a few hours of the collapse of the Bonfire, items were placed on the Bonfire logs themselves, and later, on the safety orange mesh fence erected around the collapse site became the location of the initial shrines.

The site of the tragedy becomes sacred, sometimes for a short time, or longer, as the area may become home to a permanent memorial of the event, such as the memorial planned at Ground Zero and the Bonfire Memorial at Texas A&M University. These places become more than just a place, because as more memorabilia accumulates at the shrine, the site develops two purposes: a place to leave an item and as a pilgrimage site to see what others have left behind (Grider 2001). Shrines commemorate and memorialize, but they do even more than that, as they invite participation from strangers. They are open to the public. They become places of communion between the dead and the living, based upon the personalized nature of some of the writings and other artifacts left behind (Santino 2006b). Others have called them, “Portals where the living and the dead touch each other,” (Zeitlin 2006: 106).

There is a regular vocabulary of shrine artifacts, consisting of flowers, votive candles, and a wide range of popular and material culture items appropriate to the event, including: teddy bears and other stuffed animals, balloons, t-shirts, photographs, banners, drawings, Bibles and other religious items, posters, and other writings, including condolence books and blank posters or boards beckon people to leave their own messages behind (Haney et al. 1997; Grider 2001). Altogether, these memorials are a combination of religious, secular, and highly personalized ritual items. Sometimes people just leave whatever they have in their pockets (Thomas 2006). This is different from conventional mourning artifacts, because they are not specifically tailored to the deceased.

The items left at memorials may not have anything to do directly with those who have perished, but somehow those who contribute to them find comfort from the placement of these items at the shrine. According to one study, “Facing death, either of the self or of others, has come to entail ritualized social practices that mobilize domains of material objects, visual images and written texts” (Hallam and Hockey 2001: 1). Placing a memento at a shrine gives people a sense of purpose; it is similar to lighting a candle at a church altar that is both sacred and comforting, because it makes one feel that one is doing something (Grider 2001).

Some people view these shrines as portals or platforms from which to address the deceased. Folded or sealed letters at shrines reinforce the idea of portal, as if deceased could come and read the private thoughts of individuals, within the public environment. At Jim Morrison’s grave, Jeannie B. Thomas, author of “Commemoration and Graveside Shrines” (2006) states how several the notes left at his grave site were folded or difficult to read by their placement, and people were alarmed and disturbed to see her unfold them to read and photograph them. Often times at spontaneous shrines, the notes and messages are left open for the public to read (Thomas 2006). This is not always the case, because there were several sealed and folded letters and messages left at the Bonfire Memorials.

Over time, a spontaneous shrine begins to change. As people get back to their daily lives and come to terms with the tragedy, shrines may become neglected or at least begin to show their age, as explained by one scholar,

> Spontaneous shrines lose their emotional impact and symbolic integrity when they become soggy, windblown and tattered. The removal of the ephemeral shrines signals a return to secular status of the temporarily sacred landscape which was appropriated by the shrine. Weather permitting, spontaneous shrines generally stay in place throughout the liminal period between death and burial (Grider 2001: 2).

People may continue to leave artifacts of mourning at these sites, but the quantity never compares to that of the original shrine.

Perhaps the largest and most powerful group of artifacts found at shrines are those that can be classified as paper: the letters, posters, photocopies, banners, photos, and other forms of paper. Flowers and teddy bears may give comfort to those who leave them behind, as well as those who visit the shrines, but nothing is more personalized or more powerful than the individual messages and images. And while those flowers and teddy bears tell us something about the feelings and thoughts of the mourners, nothing is more overt than the writings and the conscious choices made in the paper artifacts' creation. So many of the artifacts left at shrines are abstract, while writings and photos are a direct material culture link to the individual, both to those who have died and those mourning the loss.

Some people bring personalized notes, sealed or left exposed for everyone to view. Others bring large expanses of paper, either for others to record their thoughts at the shrine, or already inscribed banners with words and messages from others who could not come personally. Some bring clippings from newspapers or other literature. Bibles, prayer cards, and other printed materials are quite prevalent as well. Other mourners may bring paper items deemed important to the situation. At the Texas A&M Bonfire spontaneous shrines, for example, many chose to leave football tickets and ticket stubs and the programs from games.

Another interesting component is that some people consciously took the time to try to preserve the paper that they left at the shrine through lamination or framing. At Texas A&M University shrines several papers, both photocopies of photographs and other writings were laminated prior to leaving them at the shrine. This "vernacular conservation" (Grider 2007) demonstrates a lot of forethought in the choice of material to be left behind.

Because of the exposure of the outdoor shrines to the elements, the paper artifacts become severely damaged by rain, sun exposure, wind, changes in temperature and humidity, and other external forces such as dirt, grass, candle wax and fire, bug debris, and other unknown items. These forces cause paper to become waterlogged and dried, sun bleached and damaged, wrinkled, cockled, stained, burnt, and moldy to name a few of the effects of this damage. All of these problems damage the paper. If the artifacts from a shrine are to be collected and preserved for the future study of this unique mourning ritual, they must be conserved and archived.

Conservation of Bonfire Material

After enough time had passed, volunteers began to collect artifacts from the shrines. Prior to collection, they were mapped and recorded, and given individual artifact numbers. The artifacts were removed and taken to a warehouse and allowed to dry. Once dry, they were placed into plastic bags. From the thousands of collected artifacts, over 100 of the most damaged paper artifacts were selected to be conserved. The artifact reports and photos of each are in the appendix. Presented here is a selection of representative artifacts from both a conservation perspective and as a part of a spontaneous shrine. Each artifact had a conservation strategy prepared to address its individual issues, which were outlined in a conservation report with accompanying photographs before and after conservation.

The first artifact discussed here, Artifact 2000.001.6187-12, a handwritten letter on notebook paper was damaged by water, wind, dirt, mold and other items, whose effect can be seen in Figure 43. After the initial photographs were taken, the artifact was

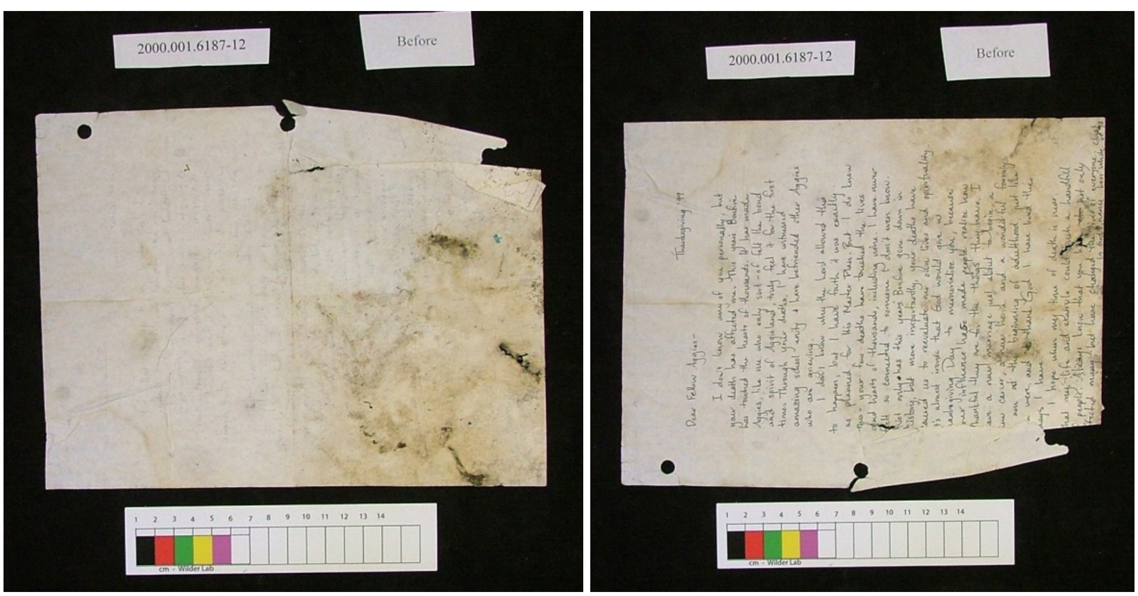
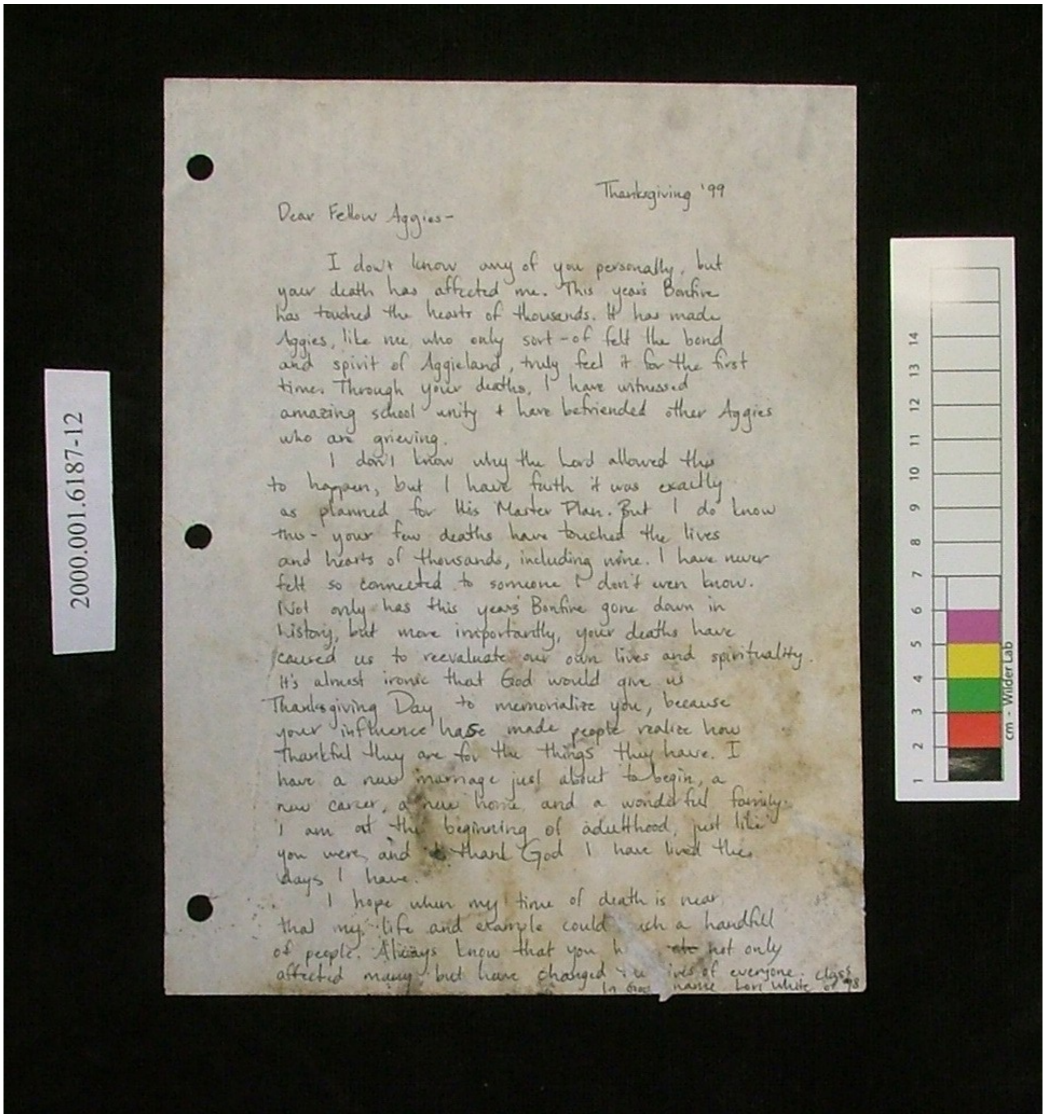


Figure 43. Artifact 2000.001.6187-12 prior to conservation.

deemed strong enough to be washed to remove the dirt and other debris. It was washed in a bath of distilled water with the addition of calcium carbonate to deposit a buffer reserve. This removed acid already present in the paper and provided a buffer to retard further acid formation. After washing, it was dried by placing it between two sheets of blotter paper and pressed by placing a tray with weights upon it. The tray was larger than the artifacts, to ensure that the artifact was flattened equally, and was placed upon the blotter/artifact sandwich each time the blotters were changed. After about two minutes, the artifact was removed and flattened between a new set of blotters. After about three minutes, the artifact was removed and placed between another fresh set of blotters. The first three pressings should remove any loose water, but the artifact was not yet dry. After about thirty minutes, the artifact was placed between a new set of blotters, and left for an hour. Blotters should be changed as needed to ensure even drying and flattening. After the artifact was dried, the torn and missing areas were mended using fill paper, cut or torn to the specific size of the area using wheat starch paste as an adhesive. Fill paper is made of a neutral cellulose base, so it will not interact with the paper artifact while providing additional strength to the torn or missing areas. Wheat starch paste is an adhesive commonly used in paper conservation since it is non-reactive as well.

While it was successfully mended, the artifact became slightly warped, so it was placed into a humidification chamber. A humidification chamber provided moisture to relax the fibers of the paper, without saturating it with water. Once the paper was humidified, it was flattened again between a series of blotters and trays, to ensure its best appearance before the application of passivation polymers. As stated before, the polymer treatment increases strength and flexibility by stabilizing the interfiber bonds and the fiber to fiber bonds by forming a strengthening matrix between the fibers. Consequently, the paper develops a memory of the shape it was when it was treated, therefore, if the paper is warped when it is treated with the polymer, it will likely remained warped. It is difficult to flatten an artifact that has already been treated with polymers.

A new solution of passivation polymers was prepared. The solution contained 95% MTMS and 5% Si oil (SFD 1), which was found to be the ideal solution based upon previous experiments. The artifact was placed directly into the solution for five minutes, and then removed and was placed between blotters and allowed to dry. The after photo of Artifact 2000.001.6187-12 can be seen in Figure 44. No catalyst was used on this or any of the papers that were conserved. Catalysts are often used with passivation polymers to ensure total penetration of the solution into an artifact and completion of the crosslinking to form a strengthening resin. Paper conserved with passivation polymers does not need a catalyst, because it is thin enough that total penetration is complete, and the ambient humidity present in the environment is enough to complete the formation of the strengthening resin. Experiments with passivation polymers have shown that treatment makes paper fungistatic. As a result, it is thought that the mold is stabilized through treatment, and further mold growth will be discouraged on the artifact. Because of its conservation and treatment with passivation polymers, this hand-written letter is no longer too fragile to be easily handled and can be studied and archived with ease.



Thanksgiving '99

Dear Fellow Aggies-

I don't know any of you personally, but your death has affected me. This year's Bonfire has touched the hearts of thousands. It has made Aggies, like me who only sort-of felt the bond and spirit of Aggieland, truly feel it for the first time. Through your deaths, I have witnessed amazing school unity + have befriended other Aggies who are grieving.

I don't know why the Lord allowed this to happen, but I have faith it was exactly as planned for His Master Plan. But I do know this - your few deaths have touched the lives and hearts of thousands, including mine. I have never felt so connected to someone I don't even know. Not only has this years' Bonfire gone down in history, but more importantly, your deaths have caused us to reevaluate our own lives and spirituality. It's almost ironic that God would give us Thanksgiving Day to memorialize you, because your influence hase made people realize how thankful they are for the things they have. I have a new marriage just about to begin, a new career, a new home and a wonderful family. I am at the beginning of adulthood, just like you were, and thank God I have lived the days I have.

I hope when my time of death is near that my life and example could [illegible]ch a handful of people. Always know that you h[illegible] not only affected many but have changed [illegible] [illegible]ives of everyone.

In God's name Lori White class of '98

Figure 44. Artifact 2000.001.6187-12 after conservation.

This artifact is a letter written by someone who did not personally know any of the people who died, but wanted to communicate with them directly. The author of the letter consciously left it open to be read by the people visiting the shrine, perhaps, communicating a shared experience of mourning that the author needed to express to help her deal with the reality of the situation. Whatever the motivation behind leaving the letter, because of the conservation, it can be handled, archived, displayed, and studied by other scholars with ease.

The next artifact, Artifact 1988/a/fea4 seen in Figure 45, is a handwritten sign that was not laminated, but placed in a scrapbook page (the type with the adhesive placed upon an acetate oversheet). The creator of this artifact attempted to make the paper message more weather resistant and lasting by encasing it in plastic. This makeshift laminate did not protect the message, and made its conservation more

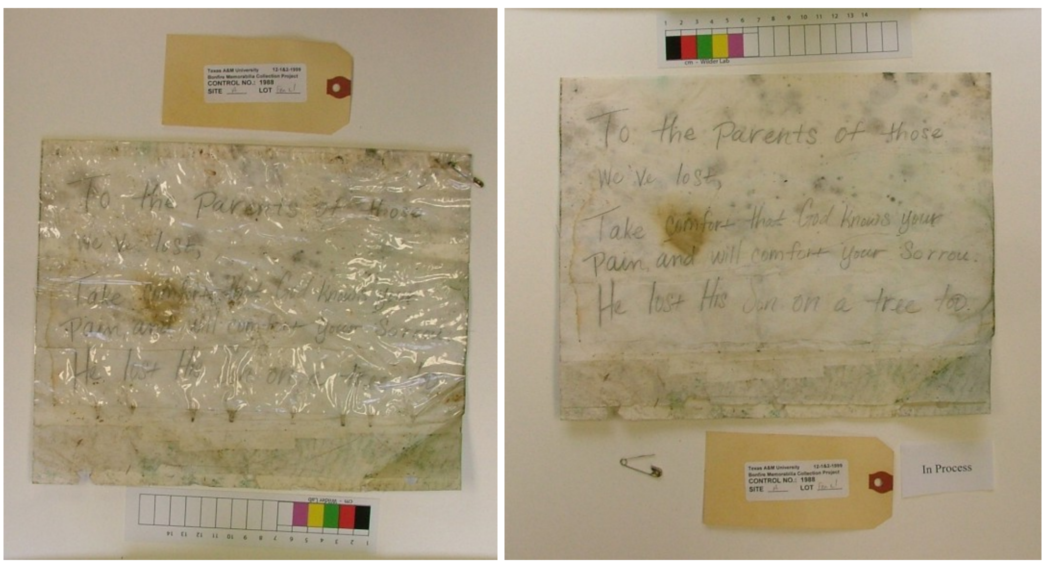


Figure 45. Artifact 1988/a/fea4 before and in the process of conservation; left to right.

difficult, because the scrap book material had to be carefully removed. Because it had been placed into the plastic sheeting, it became apparent that the plastic had sealed in enough moisture to make the perfect environment for mold growth. Candle wax, tape, and other debris were present, in addition to damage caused by a safety pin used to attach it to something. The tape and other adhesive had to be removed from the very fragile paper before any other treatment could proceed. The bottom of the paper had been taped to the back of the scrapbook page, and was especially fragile as a result. Acetone on a cotton swab was used to gently remove the adhesive from both the plastic sheeting and the tape. After the adhesive was removed, the paper was deemed too fragile to wash, so it was mechanically cleaned to remove the dirt and mold using a brush and an eraser. Following cleaning, it was placed into a humidity chamber to relax the fibers for flattening. When the flattening was complete, it was mended using fill paper and wheat starch adhesive. It was then placed into the humidification chamber and then flattened again. After it was flattened for the last time, it was decided that instead of immersing the artifact into a polymer solution, that it would be safer to spray the solution onto the artifact. Even though the solution does make paper stronger, this artifact was very weak, and the small amount of stress from the immersion process might have been enough to cause additional damage. A solution of 95% MTMS and 5% Si oil was prepared and placed into an atomizer, to ensure the best coverage. The artifact was placed onto a contact sheet of plastic, and sprayed with the polymer solution until it looked wet. It was placed between a series of blotters and allowed to dry. After treatment, the paper felt better than it did before treatment, since it no longer felt like it was going to disintegrate in one's hand, as it did prior to treatment. The artifact after treatment can be seen in Figure 46.

Artifact 1988/a/fea4 is an interesting artifact since the creator tried to make the message more permanent, which exhibits a different behavior than simply leaving a hand-written note. Additionally, the message on the paper is not for the deceased or

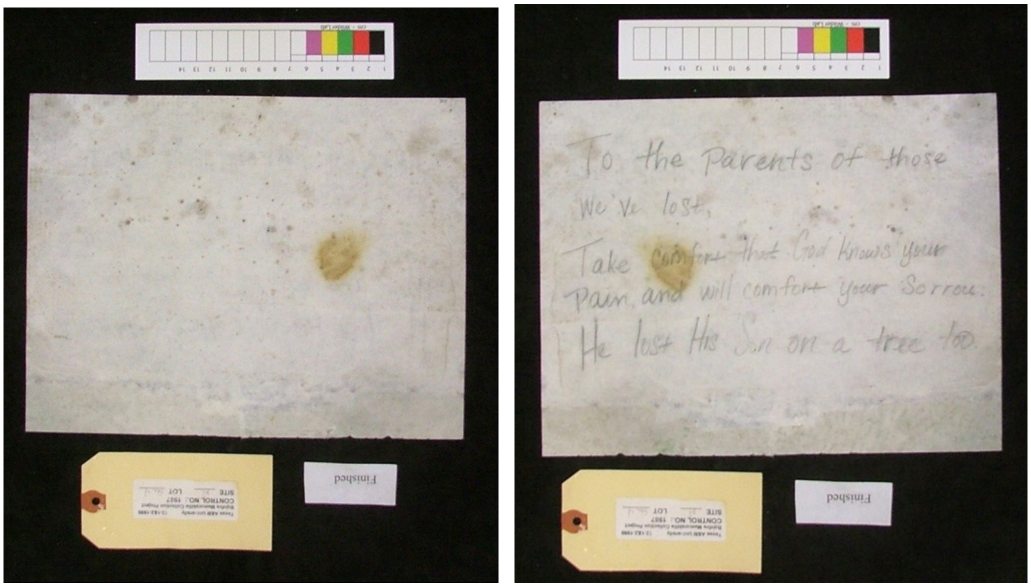


Figure 46. Artifact 1988/a/fea4 after conservation.

other unknown mourners. It is addressed directly to the parents of the victims. The individual who left this message assumed that the parents would visit the shrines, and the creator wanted to address them directly. Whatever the reason for the creation of the artifact, it has been stabilized, made stronger, and safer (due to the mold removal and fungistatic quality of the polymer treatment) through conservation.

Artifact 2000.001.6213 is a ticket stub and ribbon from the 1999 football game between Texas A&M University and the University of Texas held at Kyle field, the football stadium on the Texas A&M University campus, which took place after the bonfire collapsed. Onto it was pinned a “Bonfire Ribbon,” the symbol of remembrance adopted by those mourning. The before and after treatment photos can be seen in Figure 47. The ticket stub was in relatively good shape, but it had become waterlogged at some point, so the card stock had swollen and shrunk during the drying process. It had become moldy and covered with surface dirt. Ticket stubs are printed on card stock, which is different than ordinary paper. Card stock is thicker, and in the case of tickets, it is often layers of paper adhered to one another. Also, the surfaces of the paper are finished with a surface coating that is glossy and sensitive to heat. Tickets must be carefully made to prevent forgeries.

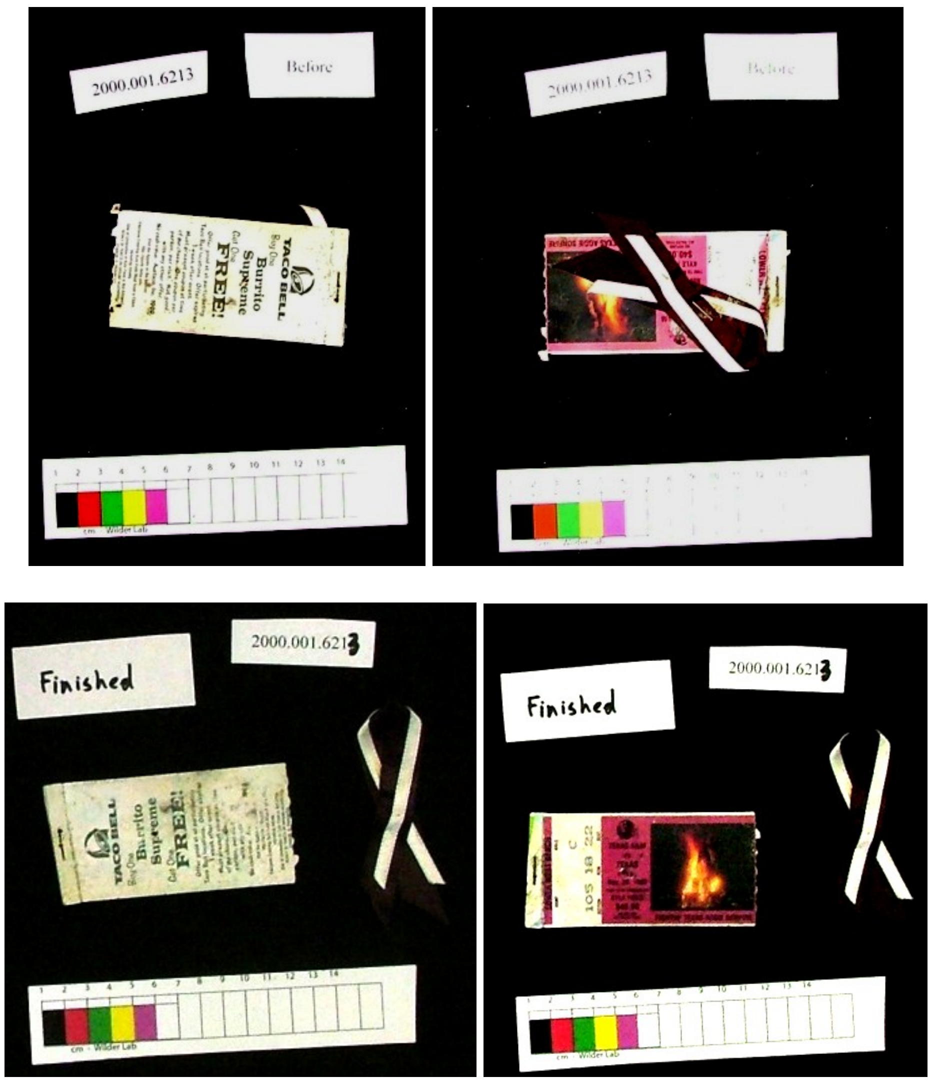


Figure 47. Artifact 2000.001.6213 before and after conservation. The before photos are on the top and the finished are on the bottom.

Since it was not possible to analyze the material of the ticket stub without further damage, it was quickly rinsed in distilled water with calcium carbonate to remove the surface dirt and mold. Washing does not remove mold, but it can remove some of the stains mold causes. It was quickly rinsed so that it would not become re-saturated with water. It was dried and flattened between blotters. After it was flattened, it was dipped into a 95% MTMS and 5% Si oil solution, and placed between blotters to dry. After treatment, it looked and felt much better, almost like a new ticket, since it was stronger and stiffer.

This composite artifact is another type of artifact found at spontaneous shrines. It does not leave an overt message of grieving, but has direct meaning within the context of the Bonfire and Texas A&M University. Someone saved this ticket stub from the football game, and felt that it and the ribbon exemplified the Bonfire tradition at Texas A&M and left it at a shrine. This could be similar to the act of placing whatever one has in their pocket at the shrine, but a ticket stub has additional significance in this situation, especially since the ribbon was attached. Ticket stubs are often considered souvenirs of an event, so leaving it is more significant than leaving a random item.

That may not be the case with Artifact 2000.001.6216, seen in the before treatment photos in Figure 48. It is a flyer for a New Year's Eve party in Houston, Texas, with a Christian theme. It did have some surface dirt and grass, and was probably waterlogged prior to treatment. It was worn, as if it was stepped upon or ground down, but the paper seemed strong. It was mechanically cleaned initially, to remove the dirt and grass, and then washed in distilled water with calcium carbonate in solution. It was

Figure 48. Artifact 2000.001.6216 before conservation.

risky to wash it, since it was made of card stock and had a glossy surface coating, but it needed to be flattened, so the risk was taken. Washing and flattening only improved it appearance, so it was placed into a 95% MTMS and 5% Si oil solution for five minutes. It was not bad shape before treatment, compared to many other artifacts, but is more stable after treatment, and its post treatment photos can be seen in Figure 49.

This artifact does not have any context within a spontaneous shrine nor is it related directly to Texas A&M University. It is assumed to have been left by a visitor to the shrine. It was found within the shrine's context, and was collected as part of the shrine.

Artifact 2000.001.6207-2 is construction paper sign that became very damaged from weathering and external debris that can be seen in the before treatment photos seen in Figure 50. The ground-in dirt held the paper fragments together, but during the first step in its conservation of mechanical cleaning by brushing, the pieces became free.

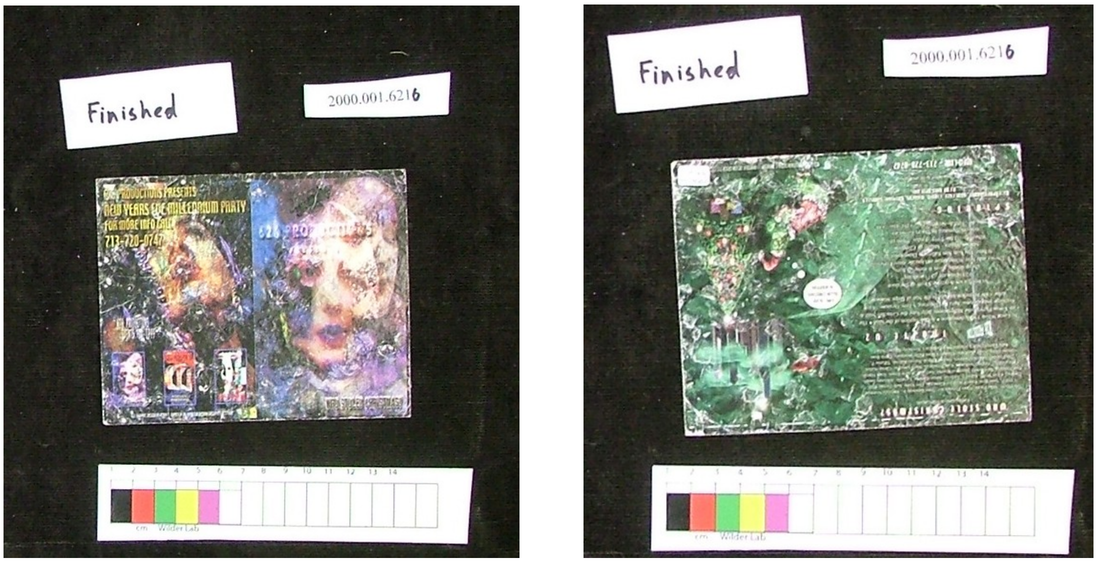


Figure 49. Artifact 2000.001.6216 after conservation.

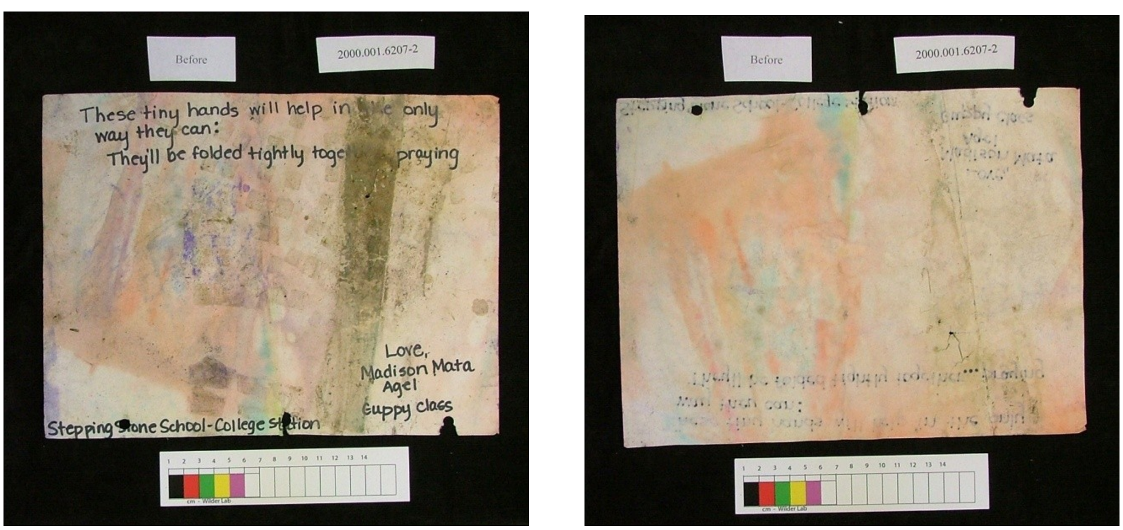


Figure 50. Artifact 2000.001.6207-2 before treatment. Each photo is labeled at the top of the image.

These fragments can be seen in the before treatment and in process photos shown in Figure 51. Since it was so fragile, it was humidified instead of washed. Washing places stress upon the paper, and it is not recommended to wash fragile paper. The humidification of the artifact allowed for further mechanical cleaning. After cleaning and humidifying, it was flattened between blotter paper. It was then mended with fill paper and wheat starch paste, gluing the torn fragments back in place. At this time the ink was tested, to ensure that the polymer solution would not cause it to run. It was flattened again and carefully placed within a polymer solution of 95% MTMS and 5% Si

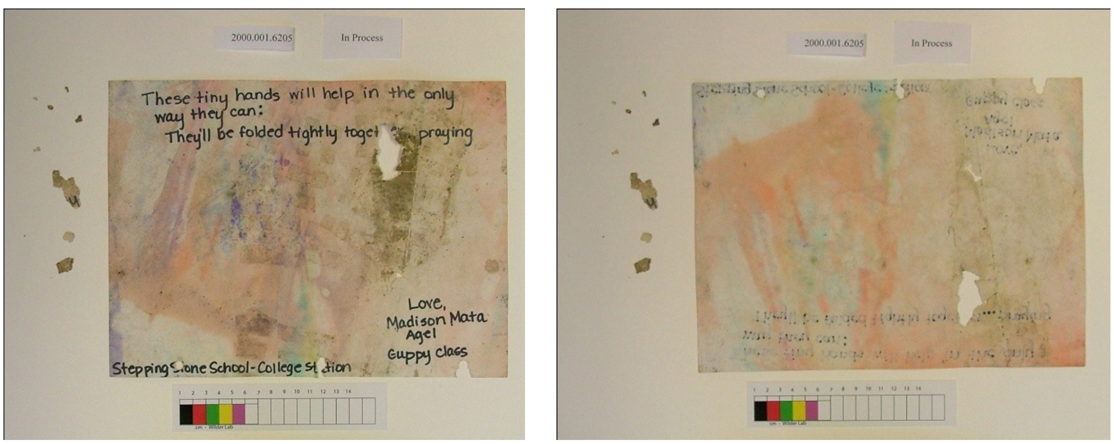


Figure 51. Artifact 2000.001.6207-2 during treatment.

oil. It became stronger and felt much better to the touch after conservation, and the mended and filled areas became more flexible because they were stronger. The artifact can be seen in Figure 52.

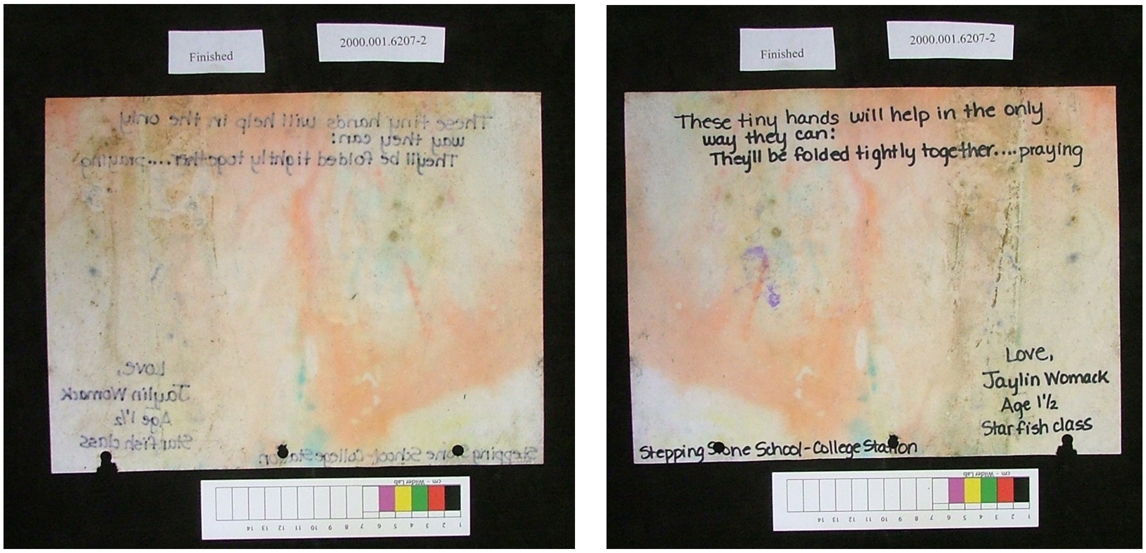


Figure 52. Artifact 2000.001.6207-2 after treatment.

This artifact portrays a different message from most. It is assumed that the central image was lost during the weathering process, but the message seems to imply that there was an image of a child's hands or artwork. After conservation and the repairs made to it during the process, it looks much better and feels stronger than it did prior to treatment.

Artifact 2000.001.6206 -a., -b., -c., and -f. is a conglomeration of four paper artifacts seen in the before photos in Figure 53. The conservation varied with each item from the greater whole. All of the items had surface dirt, mold, grass and other debris present. The first action was to humidify the bundle so that each item could be separated. Once each item was separated, it could be addressed. Some of the individual artifacts were deemed strong enough to undergo washing, while others were found to be very fragile.

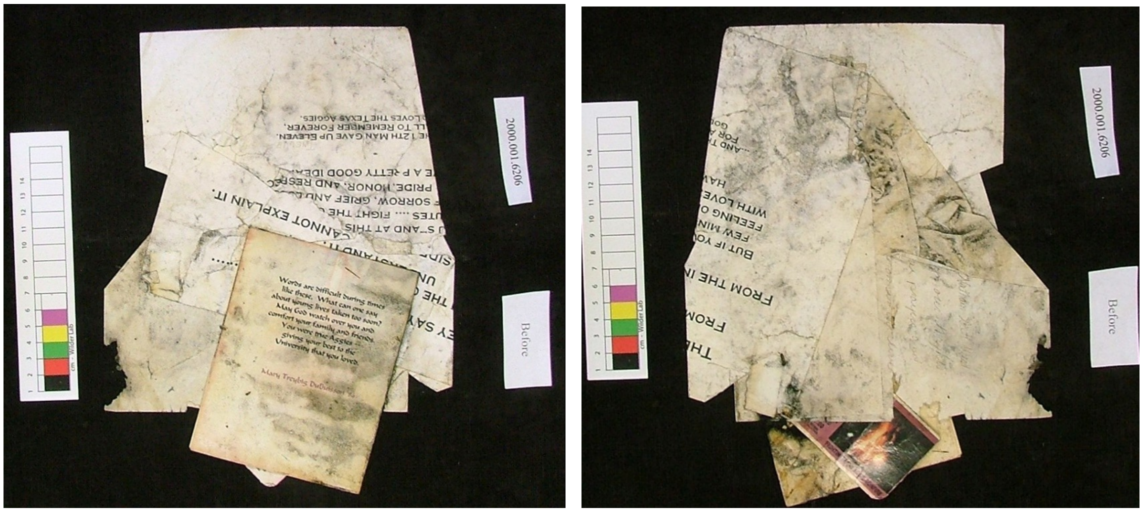


Figure 53. Artifact 2000.001.6206-a, -b, -c, and -f before conservation.

The first artifact to be addressed was Artifact 2000.001.6206-a. It is a page torn out of a spiral notebook with two or three different inks used for messages. It was coated with mold and had a number of tears and voids, which can be seen in Figure 54. It was mechanically cleaned to remove some of the mold and surface dirt. The paper was fragile, but not too fragile to be washed very carefully, so it was washed and dried between a series of blotters. After it was dried, the tears and voids needed to be addressed. It is always best for repairs to be as non-invasive as possible. Repairs should be made to strengthen the paper and to prevent additional damage from occurring to the paper as a result of a weak area. The tears and voids that were filled were deemed to be the most likely to result in larger tears and bigger voids. The voids that did not seem to pose a danger to getting bigger were not filled. The tears and voids were filled using fill paper and wheat starch paste. The easiest method of preparing fill paper to fill large or difficult voids is to place clear plastic sheeting over the artifact and trace the void on a

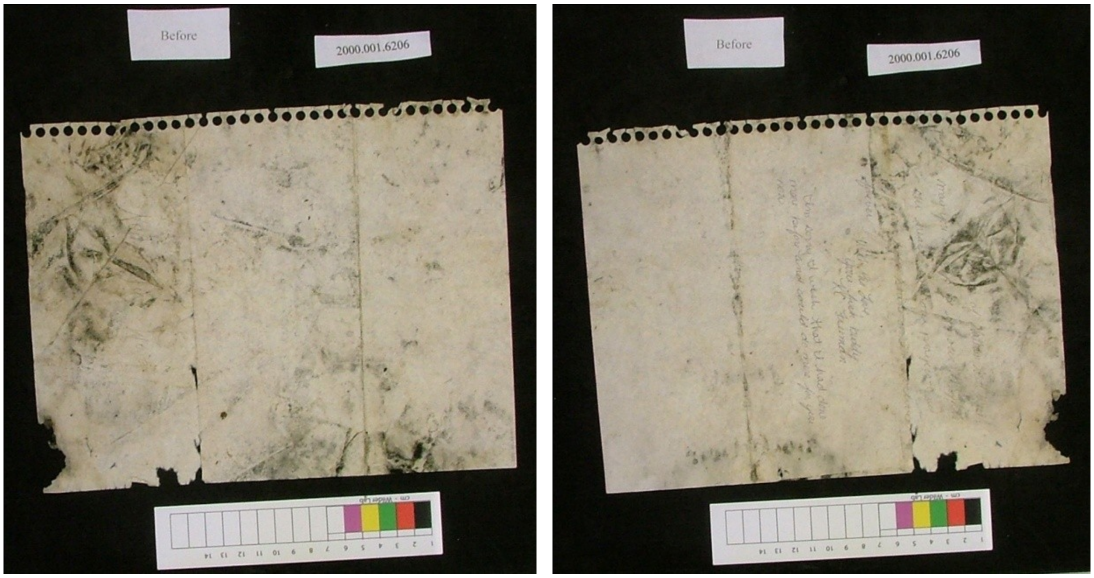


Figure 54. Artifact 2000.001.6206-a before conservation.

light table. Then, place fill paper over the tracing on the light table and using a needle tool, perforate the tracings slightly larger than the original. Tear out the shape, and the rough edges provide a large surface area to hold it and the adhesive to the artifact paper. Not all of the voids and tears in Artifact 2000.001.6202-a needed to be filled, since they were not deemed as to continue to cause additional damage to the artifact. The artifact was humidified and flattened again after mending, then placed into a polymer solution of 95% MTMS and 5% Si oil. After being dried between blotters, it felt stronger and more durable. The mold should not continue to be a threat to those handling the artifact after conservation because of the fungistatic quality of the polymer solution. The after conservation photos are shown in Figure 55.

When this artifact was presented for conservation, there was so much mold present that it was almost impossible to see any writing on the paper. After mechanical cleaning and washing, it became apparent that this artifact was a composite of at least three different messages. It is not known whether the messages were created at the shrine, or if they were created prior and then brought to the shrine. Regardless, after conservation, the artifact is much stronger and safer for handling.

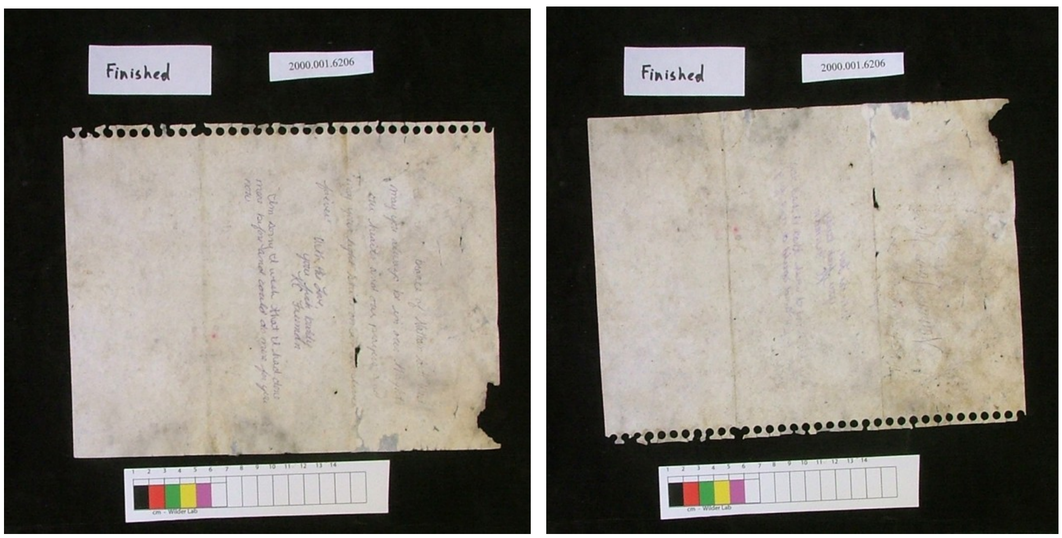


Figure 55. Artifact 2000.001.6206-a after conservation.

The next artifact from the bundle is Artifact 2000.001.6206-b is a ticket stub, seen in Figure 56. After it was removed from the bundle of artifacts, it was mechanically cleaned of its mold and surface dirt. It was quickly rinsed to remove other surface dirt and mold. Since it was made of card stock, as the other ticket stub discussed before, it was not desirable to saturate it with water, just to clean off the surface dirt and mold. It was flattened afterwards, and then placed into a polymer solution of 95% MTMS and 5% Si oil. It was strong before, and may not have needed the polymer treatment to increase its strength, but since it was moldy, the fungistatic properties of the polymer solution are important to its conservation. The finished conservation photos are shown in Figure 57.

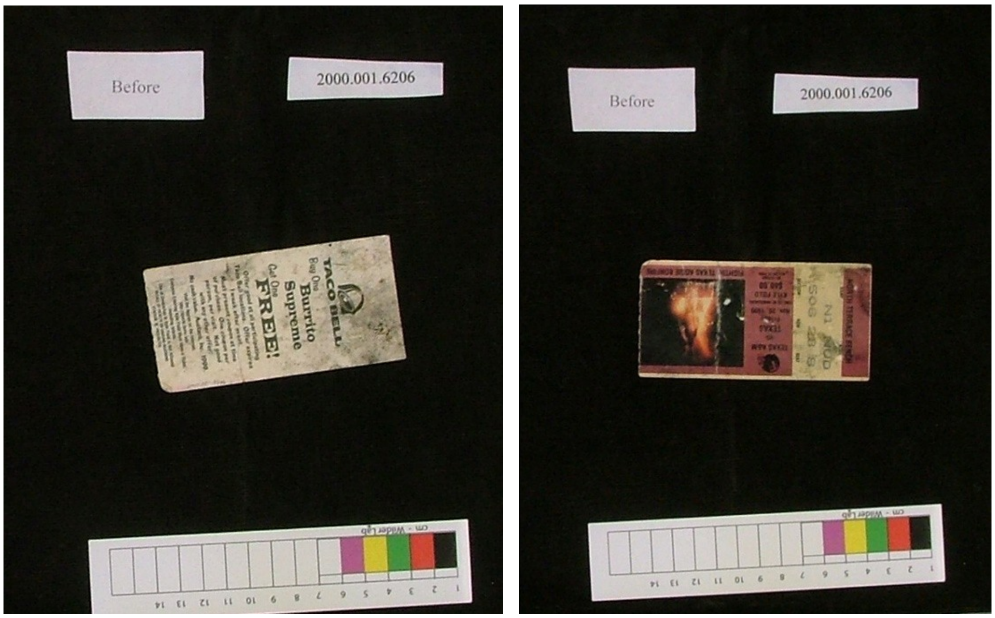


Figure 56. Artifact 2000.001.6206-b before conservation.

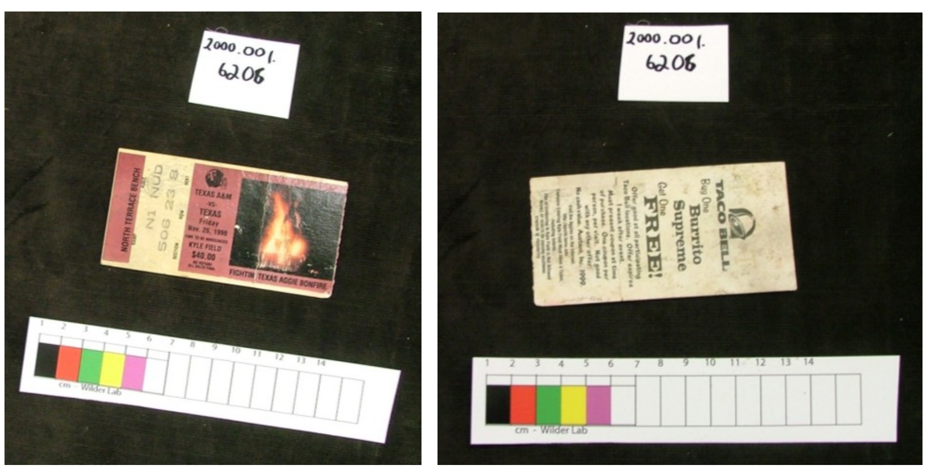


Figure 57. Artifact 2000.001.6206-b after conservation.

The next artifact conserved from the bundle was Artifact 2000.001.6206-c. When it was presented for conservation, it was covered in mold and surface dirt, seen in Figure 58. It was a thick piece paper that had been folded in half, but the interior of the fold had become stuck together. After mechanically cleaning, to remove the surface dirt and mold, it was washed repeatedly. The paper felt fairly strong, so washing it repeatedly to remove the mold and its stains was not deemed as being risky. During the washing, it became possible open the fold, but it did not open easily, and some of the paper remained stuck to the opposite side during opening. The spine had broken and was torn three-quarters of the way up from the bottom, making it likely to continue to tear. After it was cleaned and opened, it became apparent that it was a card from a memorial service. The spine was mended using fill paper and wheat starch paste.

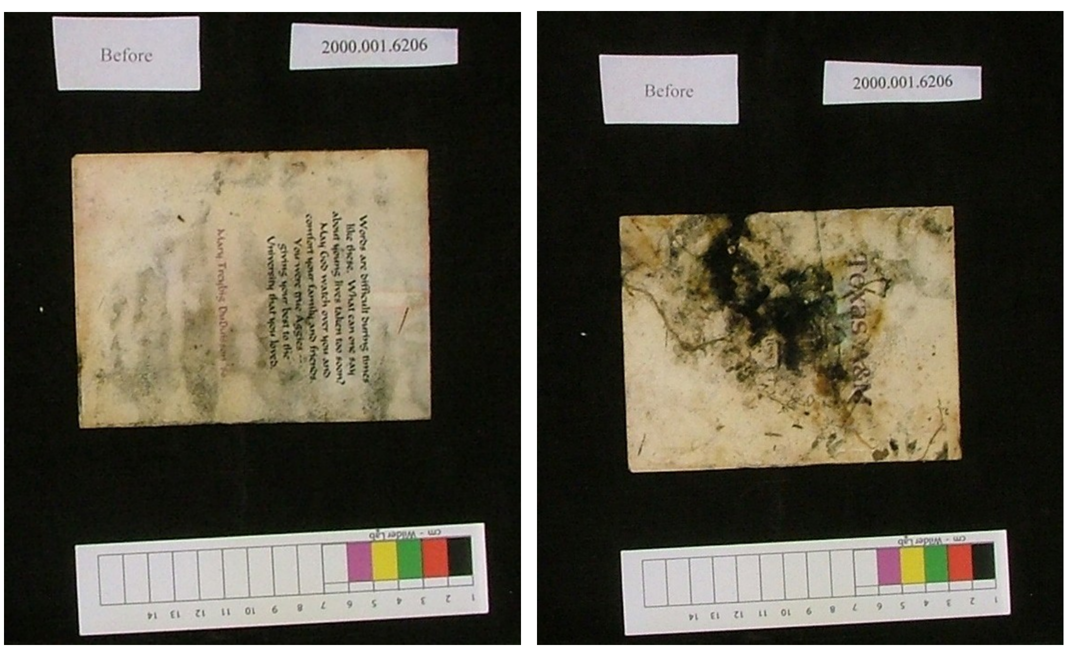


Figure 58. Artifact 2000.001.6206-c before conservation.

After the mending was complete, it was re-humidified and flattened. Even though it had been folded initially, it was immersed into a 95% MTMS and 5% Si oil polymer solution while flat. Since paper artifacts retain their shape once submitted to the polymer solution, it was decided that the mend on the spine would be more lasting if the artifact was left flat, rather than folded. The after conservation photos are shown in Figure 59. After conservation, it was possible to read the media printed on both sides. It feels stronger, flatter, and smoother.

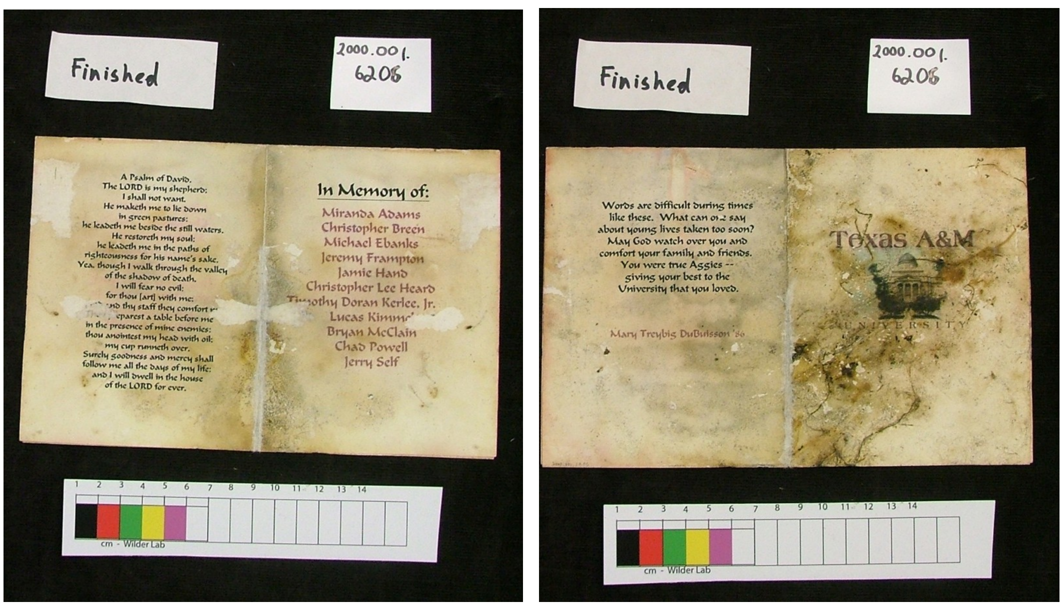


Figure 59. Artifact 2000.001.6206-c after conservation.

The last artifact in the group is Artifact 2000.001.6206-f. It is an 8½ by 11 inch sheet of white paper with computer printing upon it. It had mold and other surface dirt present, and had become yellowed. It had clear tape on it and several tears and voids and was very wrinkled. The artifact before conservation can be seen in Figure 60.

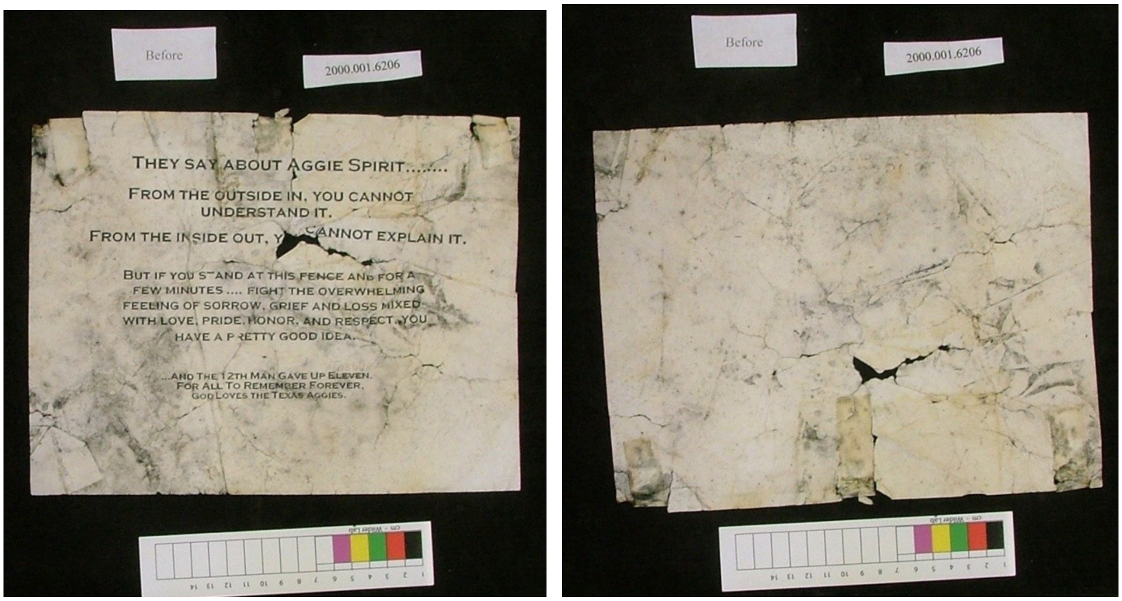


Figure 60. Artifact 2000.001.6206-f before conservation.

The first step in conservation of Artifact 2000.001.6206-f was to mechanically clean it by brushing it with a soft brush to remove some of the mold and surface dirt. Then, the tape needed to be removed because it is not only aestically unpleasing, but it had mold trapped underneath it, as well as the tape might continue to degrade the paper due to the chemicals in the plastic and adhesive. The removal was conducted very carefully using acetone and a very thin, sharp blade. The paper was too weak to have removed the tape and its residue using an eraser or mechanical method. Even though it was removed very carefully, some paper that was already torn was removed with the tape. After the tape and its residue were removed, it was decided that even though the artifact was fragile, it needed to be washed to remove the stains. It was very gently washed in only one bath and removed very carefully. It was dried and flattened.

After flattening, the voids and tears had to be addressed. It was decided that it was more logical to back the entire artifact with fill paper, using wheat starch paste as the adhesive. Backing is only recommended when the paper is very weak or has significant tears, missing sections, or many fragments. When mending a void or a tear, each little mend has to be tailored to fill the area that is missing or torn. By backing the entire work, not only is the weak paper supported, but tears and missing sections are both addressed. The downside to backing is that it takes away the feel of the paper, and if there is media on both sides, one side must be sacrificed since it will be difficult to see through the fill paper. This was not a problem with Artifact 2000.001.6206-f since there was no writing on the side that was backed. The artifact felt very soft and weak, and would easily tear if any stress was placed upon it.

After backing the artifact, it was humidified and flattened for a final time. Because of the backing, it felt much stronger and durable, but in order to take advantage of the additional strength and fungistatic properties that the polymer solution provides, it was immersed into 95% MTMS and 5% Si oil. After sufficient time had passed, it was removed and placed between blotters to dry. After it had dried, the artifact felt thicker and stronger than it had originally, because of both the backing and the polymer solution. The artifact did not feel as soft and loose as it did prior to conservation. After conservation it felt smoother and more compact. The finished artifact can be seen in Figure 61.

This conglomerate of paper artifacts is not uncommon at shrines. While it is not thought that the individual papers were purposely stuck together, it is most likely the result of the dirt, mold, rain, and other environmental factors that caused them to become bound together. Separation of a group of artifacts like this one should not be undertaken during collection. It can cause unnecessary damage to the artifacts, and cause a spreading of the mold that was present creating a health risk for the collector.

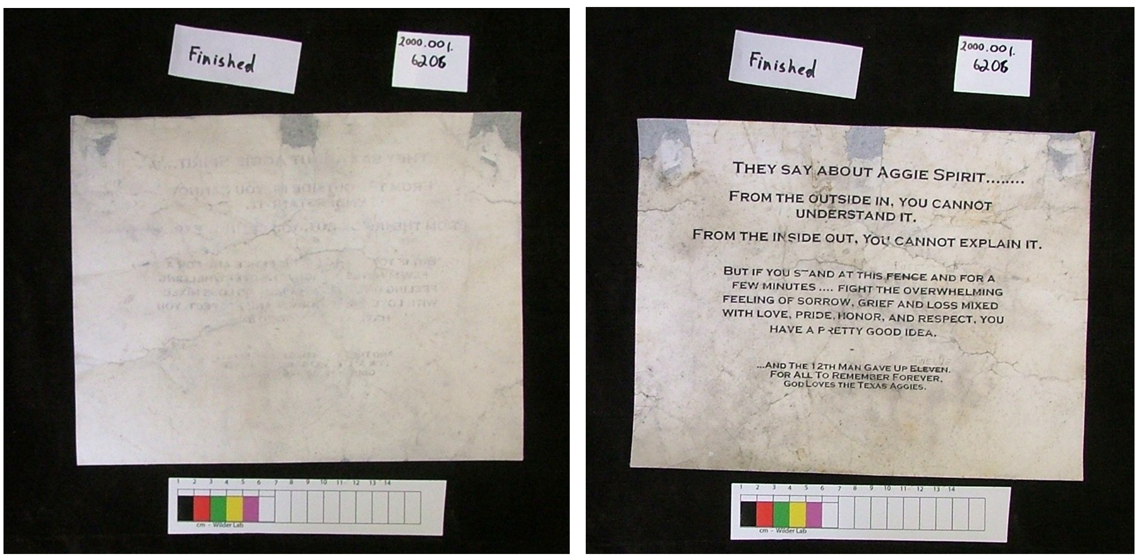


Figure 61. Artifact 2000.001.6206-f. after conservation.

Artifact 2000.001.6187-11, a letter with eight different handwritings on plain white paper, is another type of artifact left at a Bonfire shrine. Even though it had missing areas and small tears, it seemed strong enough to wash. Before washing, it had a lot of surface dirt on it, and it appeared yellowed. The photos of the artifact before conservation are shown in Figure 62. The conservation began with mechanically cleaning the surface by brushing. Next, it was washed in a distilled water and calcium

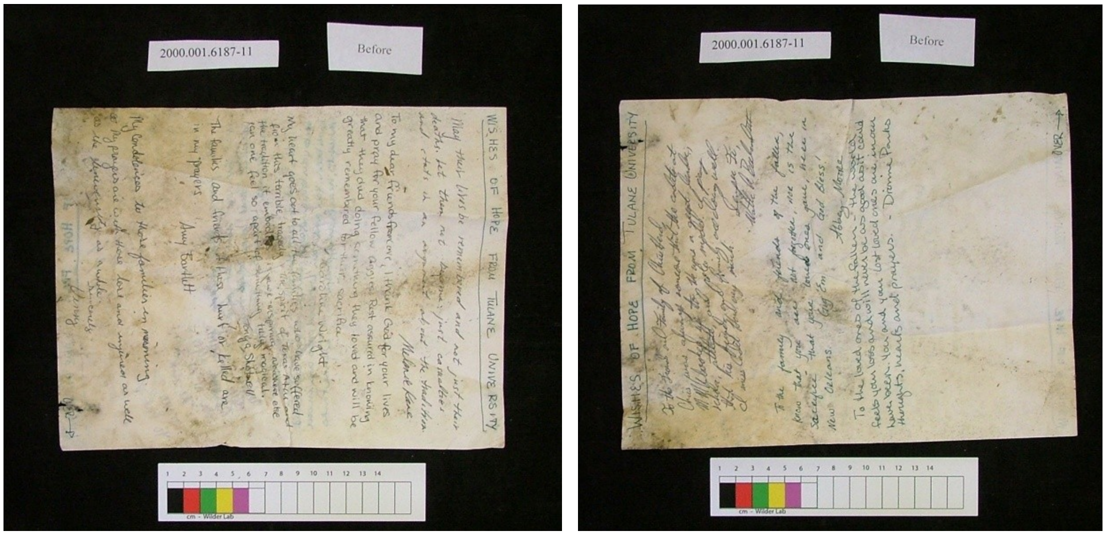


Figure 62. Artifact 2000.001.6187-11 before conservation.

carbonate baths repeatedly to remove stains and mold. Then, it was dried and flattened between blotters. After washing and drying, it looked much better and less yellow, but it still felt weak. It was mended using fill paper and wheat starch paste, humidified and flattened again, and then submitted to a polymer solution. While passivation polymers are easy to use, they are expensive, so creating a new solution for every artifact is not cost effective. Unfortunately, MTMS evaporates easily, so even if a solution was 95% MTMS when created, over time the solution has a lower percentage of MTMS as it evaporates. When Artifact 2000.001.6187-11 was initially submitted to the polymer solution and dried, it appeared to have a darkened, translucent quality, which was the result of the solution having too high a concentration of Si oil from the evaporation of MTMS. In order to remove the excess, loose Si oil, the document was retreated with a 100% MTMS solution. This does not mean that the Si oil would have been washed out; some would have remained due to the creation of the strengthening matrix. After the second treatment in 100% MTMS and drying, the artifact looked better and felt much stronger. The photos taken after conservation can be seen in Figure 63.

The top line of this artifact says, “Wishes of hope from Tulane University,” with messages from eight individuals. This is a unique artifact for two reasons. First, it has eight different messages, signifying that an individual or group organized other people to provide a message for the shrine. This makes it a composite work, created prior to its placement at the shrine, probably not made at the shrine. Second, the letter had to get to the shrine. There is no evidence of it being mailed, opened, and then placed by someone else at the shrine. This scenario is possible, but it is also possible that someone came from the Tulane University area (New Orleans, LA) to mourn at the shrine and place this letter there.

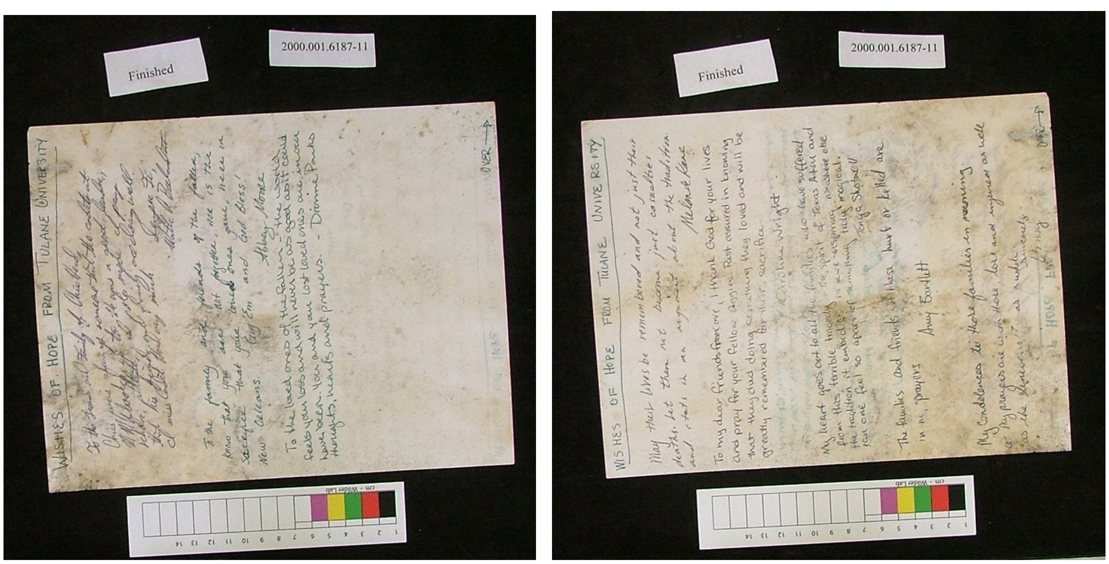


Figure 63. Artifact 2000.001.6187-11 after conservation.

Artifact 2000.001.6190, titled “We love you Jeremy!” is a collage of printed photographs on tan construction paper, shown before conservation in Figure 64. It was originally enclosed in a plastic sleeve to protect it, but the sleeve served to provide the perfect environment for mold growth. Once removed from the plastic sleeve, the whole artifact was very stiff and inflexible and the photos pulled away from the paper if it was bent. The construction paper had become warped from its exposure to the environment. After the artifact was brushed to mechanically clean, it was humidified to remove the photos from the construction paper, as shown in Figure 65. After the ink was tested for solubility in both water and the polymer solution, the photos and the construction paper were washed to remove the paste and surface dirt, and to provide a buffer to combat

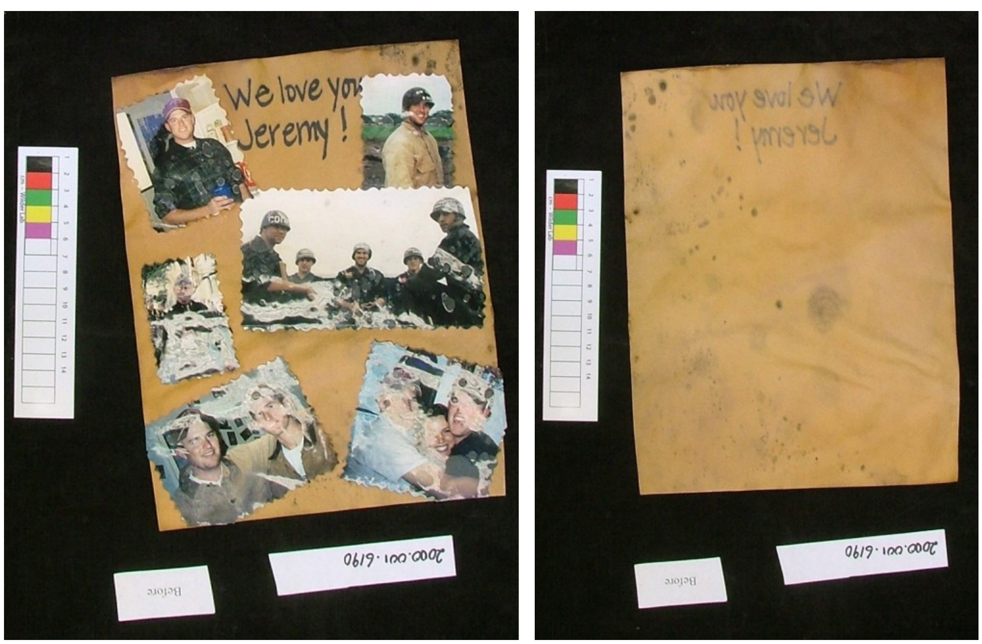


Figure 64. Artifact 2000.001.6190 before conservation.

Figure 65. The removal of the photos before washing Artifact 2000.001.6190.

acids formed in the paper. After washing, the photos and the construction paper were dried and flattened between blotters and weights. The photos were reattached in the same places using wheat starch glue and flattened again. After the final flattening, the entire piece was placed into a polymer solution of 95% MTMS and 5% Si oil. Prior to treatment, the whole artifact was very stiff and the photos were not very flexible and pulled away from the paper if it was bent. After treatment, the whole became much more flexible and the photos were better anchored to the construction paper due to both the wheat starch paste and the polymer treatment. The photos even retained their glossy quality. The post-construction photos can be seen in Figure 66.

Often, the people who contribute to shrines do not know victims personally, but this is not always the case. Artifact 2000.001.6190 was most likely left by a person who knew the individual based upon the content of the artifact. The creator of the artifact was able to collect photos showing Jeremy, one of the victims of the accident, who is shown wearing A&M apparel or in his "pot," a hardhat specifically worn when building the Bonfire, demonstrating through this collage the kind of person Jeremy was: a devoted Aggie who died performing an Aggie tradition.

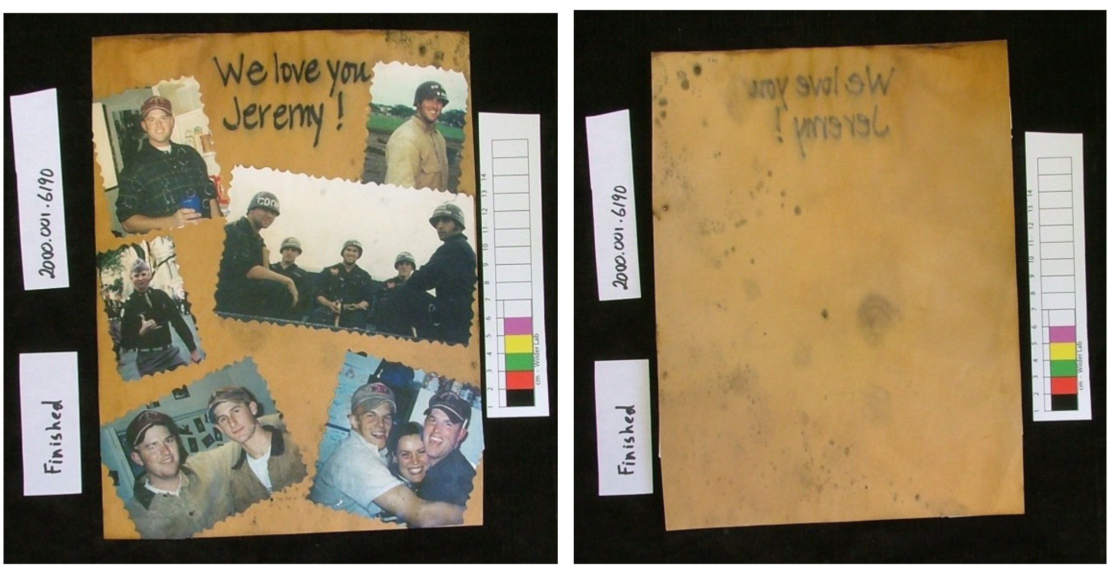


Figure 66. Artifact 2000.001.6190 after conservation.

The final artifact discussed here, Artifact 2000.001.3832, is a large poster that many different individuals wrote messages on using several different media. The poster was placed upon the ground, and other artifacts were set upon it. When the artifacts were collected, the poster was wet, so it was scraped off the ground using a shovel and placed into a collection bag. Luckily, the bag was not sealed, and the poster was allowed to air dry, which prevented additional mold growth. Figure 67. shows the poster wadded poster as it came to the conservation laboratory.

Figure 67. Artifact 2000.001.3832 before conservation. The bundle was approximately 1½ ft by 1ft.

The first step in the poster's conservation was to manually unravel the poster as much as possible, shown in Figure 68. During these early stages it became apparent that part of the poster had been burned, which can also be seen in Figure 68. The poster was not very flexible; so much of the unraveling process had to be assisted with humidification. Humidification chambers were used initially, then humidification in bags, and as the poster became too long, a fine mist of water was sprayed on using an atomizer. This did not waterlog the paper, but made it slightly damp on one surface. Figure 69 shows unraveling of the poster when it became too big to continue to be humidified in bags. Initially it was thought that the poster would have been torn into sections during its exposure or collection. This was not the case, and the poster was

Figure 68. The poster in its early stages of unraveling. It became appartant that sections of it had become burned, clearly shown in the photo on the right.

Figure 69. As the poster became more untangled, it became too long for humidification chambers.

remarkably intact, which made it necessary to find other methods of humidification. Figure 70 shows the first steps in flattening the poster between blotters, trays, and weights. Lead weights and mason jars filled with water were used as weights.

Figure 70. Sections placed between blotters and pressed to flatten with weights placed on trays.

It soon became apparent that a larger area for assemblage was necessary. Several tables were positioned together in a hallway. Sheets of spun polyester were placed upon the tables to provide support for the weak paper. Since a large portion of the poster was one continuous piece, it was necessary to flatten it intact. This process is shown in Figure 71. Figure 72 shows the burned section flattened. After the flattening was completed, the poster measured 123 inches by 37 inches. The available backing paper was not wide enough, so two sheets 130 inches long were joined together using wheat starch paste. The poster was carefully backed to the paper using the same paste. Backing the poster was the most logical decision, since the paper was very weak and

Figure 71. The left photo shows the poster placed onto tables in the hallway. The right photo shows the flattening the paper in the hallway by the author.

there were many large voids. The backing was necessary because it would not have been possible for the poster to support its own weight without tearing, and since there was no media on the back, no information was lost by backing.

Figure 72. Images of the flattening in the hallway. Note the burned sections.

Even though the poster adhered to the backing paper, it was still very stiff and could not be rolled without cracking the poster, especially the burnt areas that broke instead of flexed. The final step in the poster's conservation was spraying a 95% MTMS and 5% Si oil polymer solution onto it. The effect of this was immediately apparent. The poster became more flexible and stronger. It was able to be rolled without fear of the poster cracking or pulling away from the backing. The poster could be handled, displayed, or stored easily. The finished poster and its flexibility can be seen in Figure 73 and Figure 74.

Figure 73. The poster prior to backing (left) and moving the poster once backed and treated (right).

This poster provides an example of extreme paper conservation using passivation polymers. The poster, prior to conservation, was highly damaged from the environment and other agents, including a burned section, and from its collection and storage. The conservation of this poster was very complex and labor intensive. It was possible to flatten it and paste it to the backing paper using conventional methods.

Unfortunately, if the poster's conservation had stopped at that point, the poster would have still been very weak. It would not have been advisable to roll up the poster or move it, as the paper would have cracked, broken, and possibly fallen off of the backing paper. Treatment with passivation polymers made even the weakest parts of the poster strong enough to be flexible. Because of conservation using passivation polymers, the poster is strong and stable enough to be stored, archived, and displayed with ease.

Conclusion

The conservation of items left at spontaneous shrines becomes especially important in light of the significance of the shrines' meaning. Paper artifacts from outdoor shrines are severely damaged by wind, sun exposure, rain, mold and other intrusive items like dirt, hair, leaves, grass, and candle wax and the burns that result. Passivation polymers are especially effective for the conservation of severely damaged paper from these situations. In many cases, the paper was made so brittle by the damage incurred from the shrine's exposure that it broke when it was flexed. Yet, these same papers were made flexible by treatment with passivation polymers.

The Bonfire artifacts provided an excellent case study for the use of the polymer solution in the treatment of severely damaged paper. It has been only five years since the original conservation of these artifacts, and they look as good as they did when they were first conserved. By conserving these artifacts, future researchers will be able to study this trend in mourning and the artifacts can be handled with ease because they were conserved with passivation polymers.

Figure 74. After treatment photo of Artifact 2000.001.3832.

CHAPTER VIII

CONCLUSION

The field of paper conservation has developed many techniques that are effectively used to conserve relatively stable paper, but other methods are needed to conserve paper severely damaged by waterlogging, mold, and internal acidity. The traditional conservation techniques do little to nothing to increase the strength, flexibility, or stability of the damaged paper during or after its conservation. The problems of conventional conservation are addressed or prevented by the use of passivation polymers as a part of the conservation treatment protocol. Using functional silicone oils to treat severely damaged paper results in a stronger, flexible, and more stable paper.

Passivation polymers have been successfully used to conserve organic artifacts, especially cellulose-based artifacts. Cellulose artifacts treated using passivation polymers regain strength and stability as a result of the resins formed within the internal structure. These resins are not heavy and do not bulk the structures. Paper achieves greater stability as the carbonols on the cellulose chains are bonded with the polymer solution. Strength is added to paper by the creation of a strengthening polymer network, formed by the reaction of passivation polymers to the cellulose chains, to each other, and to the polymers within the matrix of the artifact.

Waterlogged paper is challenging to conserve. Whether recovered from archaeological contexts or from a recent disaster, it is compromised and very fragile.

Repeated episodes of wetting and drying compromise the paper even further. High levels of humidity negatively affect paper, similarly to waterlogging. When water is introduced to paper, there are several different effects. Water causes chemical reactions on a molecular level, increasing rates of hydrolysis, oxidation, and crosslinking, and causing changes in the crystalline and amorphous areas of the cellulose structure. Water causes modifications within the fiber network as well. It causes a breaking of the fiber to fiber bonds, resulting in a loss of strength. Wet paper retains only 3-8% of its original strength, and even after drying by the techniques of air drying, pressing and restraint drying, freeze drying, vacuum freeze drying, thermal drying and organic solvent dehydration, it is not as strong as it was when it was originally created, nor does it have the same texture.

Passivation polymers conserve paper damaged by waterlogging or high humidity by restoring strength to the weakened matrix, which results from a disruption of both the interfiber bonds and the fiber to fiber bonds. A requirement of using passivation polymers is that the paper must be dry prior to submission to polymer treatment. Paper that has been dried using any other drying method, like vacuum freeze drying (recommended for large quantities of waterlogged material), is much weaker than it was before waterlogging and drying. After polymer treatment, strength and flexibility is restored, and the paper can be handled without special consideration.

Another problem that can arise from water damage is mold. Mold infestations occur as a result of water or high humidity situations. Mold is especially insidious since it damages paper by ingesting cellulose and excreting damaging byproducts onto the paper. Mold is dangerous to people as well. There are many cellulose-eating molds that cause illness and, in extreme cases, even death. The conventional method of mold removal kills the mold using toxic chemicals. This treatment is both a costly and dangerous method. Even after the mold is killed, there are toxic residues left behind. The controversial technique of irradiating books and papers infected with mold effectively kills the mold colonies, but leaves the paper damaged and weakened from the effects of the radiation.

Passivation polymers can be used in two ways to solve some of the problems of the treatment of a mold infestation. It is generally acknowledged by the conservation community that there is no safe chemical eradication treatment for mold. Even though some conservators would not recommend irradiation, it is the safest treatment for materials that will be accessed by people. Unfortunately, radiation causes damage to papers, especially in large doses, such as those used by the United State Postal Service to kill biological agents. It is thought that the paper is suffering from an increase in the rate of oxidation, which can lead to an increase of the rates of hydrolysis and crosslinking. The stability and the strength restored by passivation polymers would halt the continued deterioration of these chemical processes. Additionally, polymer-treated paper has fungistatic properties. Paper that has become weakened from a mold infestation and was then treated by conventional methods becomes more easily infected again than paper that has never had a mold issue. The fungistatic properties would prevent this issue, and provide resistance to mold in paper that was treated for another damaging agent.

Internal acidity affects a large number of the extant papers, especially if their composition is wood based. The acidic compounds present within the paper are increasing the rates of hydrolysis, oxidation, and crosslinking, each of which can cause an increase in the rates of the other damaging reactions. The rates of the deterioration due to internal acidity can increase in situations of heat, light and humidity. The treatment protocols seek to neutralize the acidic compounds by introducing an alkali buffer. Individual papers can be washed in distilled water with an alkali buffer. This is effective and raises the pH and removes some of the acidic compounds. This is not possible with a bound book. It is believed that 25-40% of the books held by libraries are so damaged by internal acidity that the pages would fail if folded. Several different methods have been developed to raise the pH of bound books, most of which deposit a buffering agent within the pages of the books. But none of the treatments return the strength that was lost during the deterioration of the paper.

The results of the experiments using passivation polymers to deacidify are excellent. Not only is an alkali buffer added to the matrix, meeting the requirements of the Library of Congress, but the paper is made more stable and stronger. Stability is achieved by both the introduction of a buffer and the reaction of the polymer solution to the carbonols produced during hydrolysis and oxidation. The polymer resins created from these reactions and others form the polymer network that strengthens the matrix of fibers within the paper.

Severely damaged paper can often suffer from a combination of waterlogging, mold, and internal acidity, such as the artifacts from the Bonfire spontaneous shrines.

These papers were successfully conserved using a combination of established paper conservation treatments and passivation polymers. Many of the artifacts would require very careful handling if they were conserved using only traditional methods. Some could not have been handled at all after some time had passed, as their issues would have continued to degrade the paper until it was lost entirely. By treating the artifacts with passivation polymers, they are more stable and durable, and can be displayed, archived and handled easily. Their useful life has been extended significantly, and they are available for study to researchers interested in understanding the social significance of these unique memorials.

Paper damaged by waterlogging, mold, and internal acidity is better conserved if passivation polymers are a part of the treatment protocol. The conservation treatments of the past can be used in conjunction with passivation polymers to create better conservation treatments. Passivation polymers should be used in the conservation of severely damaged paper because they restore strength, flexibility, and stability to compromised paper.

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APPENDIX A

Experiment 1

Hypothesis: A specific solution of MTMS and silicone oil must be found to be the best solution for conserving paper.

Problem: It is not know what percentage MTMS and silicone oil would provide the best solution for the conservation of paper.

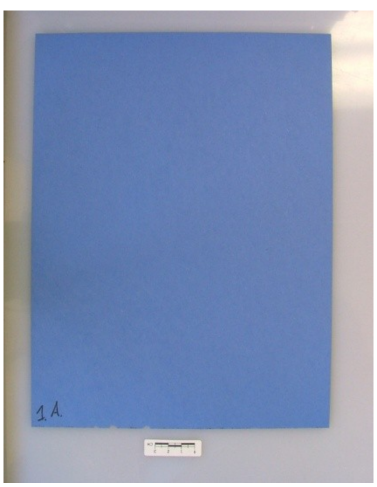
Equipment:
Construction paper
Printer paper
"Butcher paper" the paper used to wrap food at the market
SFD 1 Polymer
MTMS crosslinker
Containers for solutions.

Data: 5 different solutions were prepared by weight:

1. 100% MTMS + no Si oil
2. 95% MTMS + 5% Si oil
3. 60% MTMS + 40% Si oil
4. 20% MTMS + 80% Si oil
5. 0% MTMS + 100% Si oil

10 different construction papers were selected

1. Blue 2. orange 4. pink



5. Red

6. Brown

7. Black

8. purple

9. Yellow

10. Manila

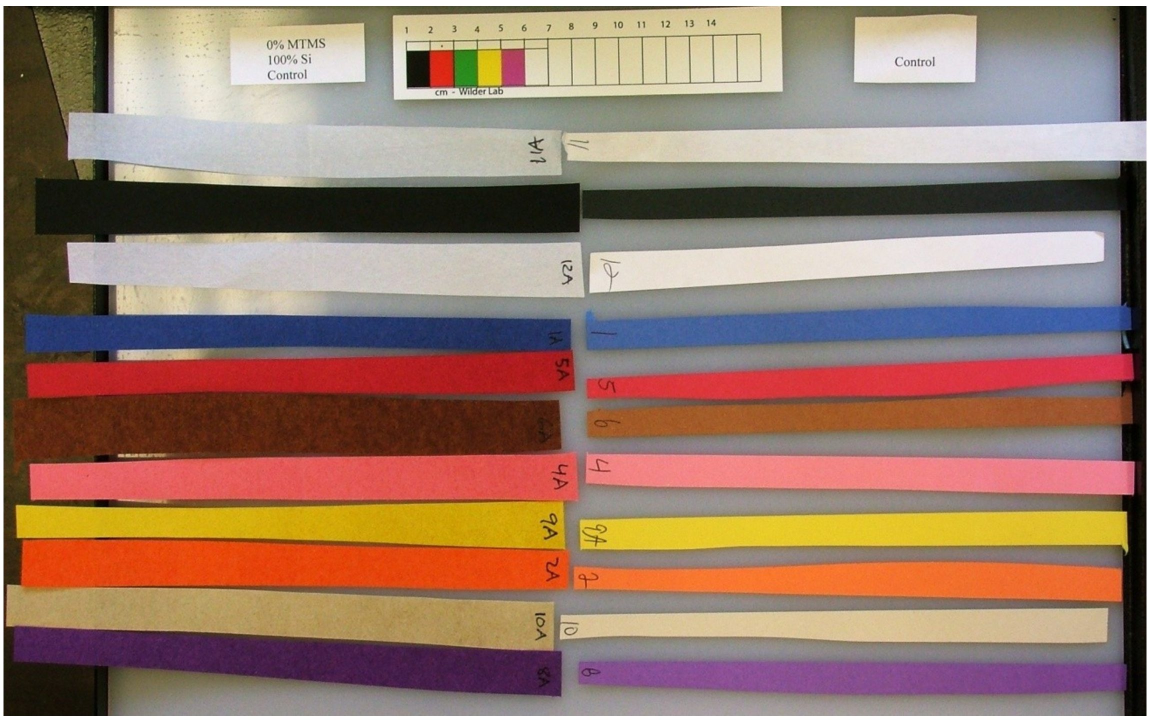
Also selected was additional paper, but the control photos are not available, but they were compared and are visible in the after treatment photos.

11. Butcher paper
12. Copy paper

Procedure: Each paper was cut into strips and labeled. A control from each was set aside. The experimental paper was placed into each solution. They remained in solution for a week. After that they were removed and blotted over a period of five months, to remove any residual treatment solutions, and to be certain that the reaction was finished. These were compared to the control untreated. These were compared based upon flexibility, texture, color, creasing, tearing, and a written description. Creasing refers to folding a place along each strip and then placing it into solution. The control was also folded. This was conducted to test the rigidity of the resins formed within the paper, and to see if the paper had a memory of its shape prior to treatment.

Data:
Comparison of treated and untreated controls:
Since the controls are the ideal consistency, the treated are compared to them as an ideal condition. Each treated paper was compared individually to the corresponding control. It was found that all of the samples had the same qualities when compared to the controls, unless otherwise noted. As a result, the comparison is recorded for the group of samples.

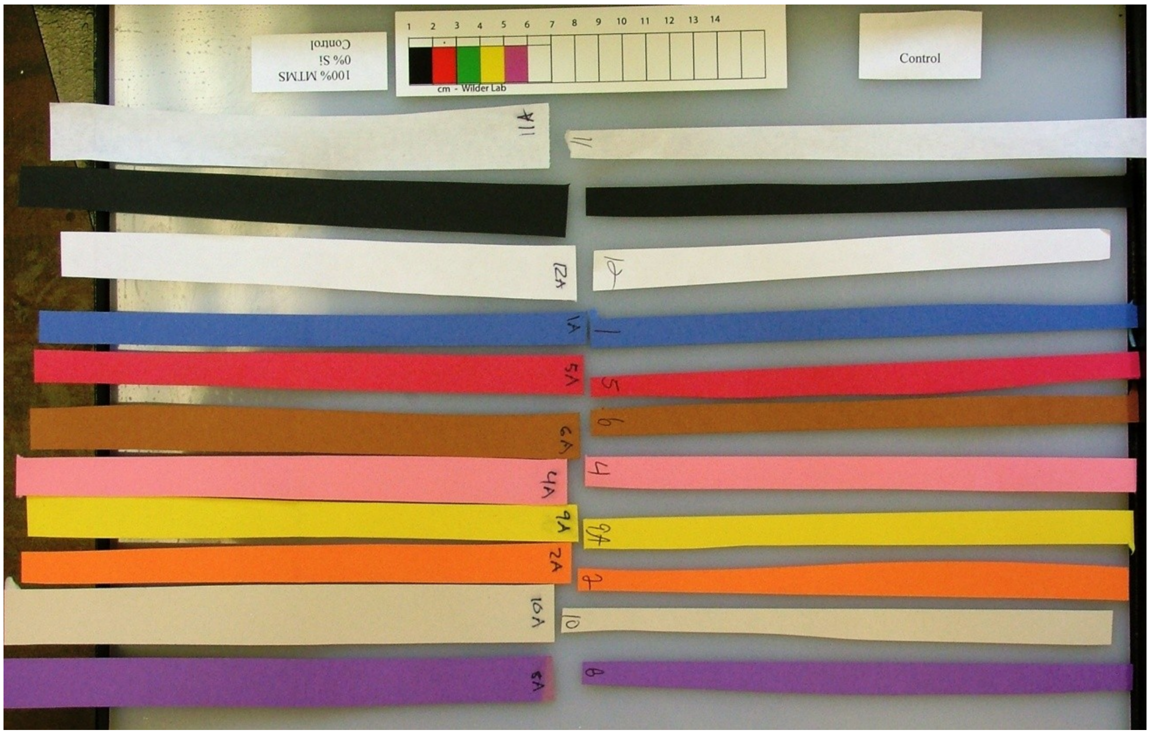
0% MTMS + 100% Si



Flexibility: Compared to the control, it is flexible, but not quite as flexible as the control, and has a tendency to want to peak/fold, instead of curve.
Texture: Compared to the control, it feels thicker and much slicker. The control has a rough quality to it. It is distinctly different.
Color: Compared to the control, the color is darker and you can see fibers of the paper with the naked eye. While it is not visibly unpleasing, it is not like the control.
Creasing: Compared to the control, you can see and feel a permanent crease line.
Ink marks: none
Tearing: Compared to the control, it tears much easier. It seems like the control has a certain amount of resistance, but the treated tears very easily.

Note the darkening of the construction paper samples. The white butcher paper and the white printer paper were thinner than the construction paper, and have taken on a translucent quality.

100% MTMS + 0% Si



Flexibility: Compared to the control, it is the same.
Texture: Compared to the control, it is the same.
Color: Compared to the control, it is the same.
Creasing: Compared to the control, you can still feel a crease line.
Ink marks: none
Tearing: Compared to the control, it is the same.

The paper appears to be the same, and feels the same. The exception to this is in the crease line.

60% MTMS + 40% Si

Flexibility: Compared to the control, it is not as flexible
Texture: Compared to the control, it is thicker and slick/waxy
Color: Compared to the control, the color is darker and the fibers are easier to see
Creasing: Compared to the control, you can see the crease, but not really feel it
Ink marks: Compared to the control, none
Tearing: Compared to the control, easier to tear

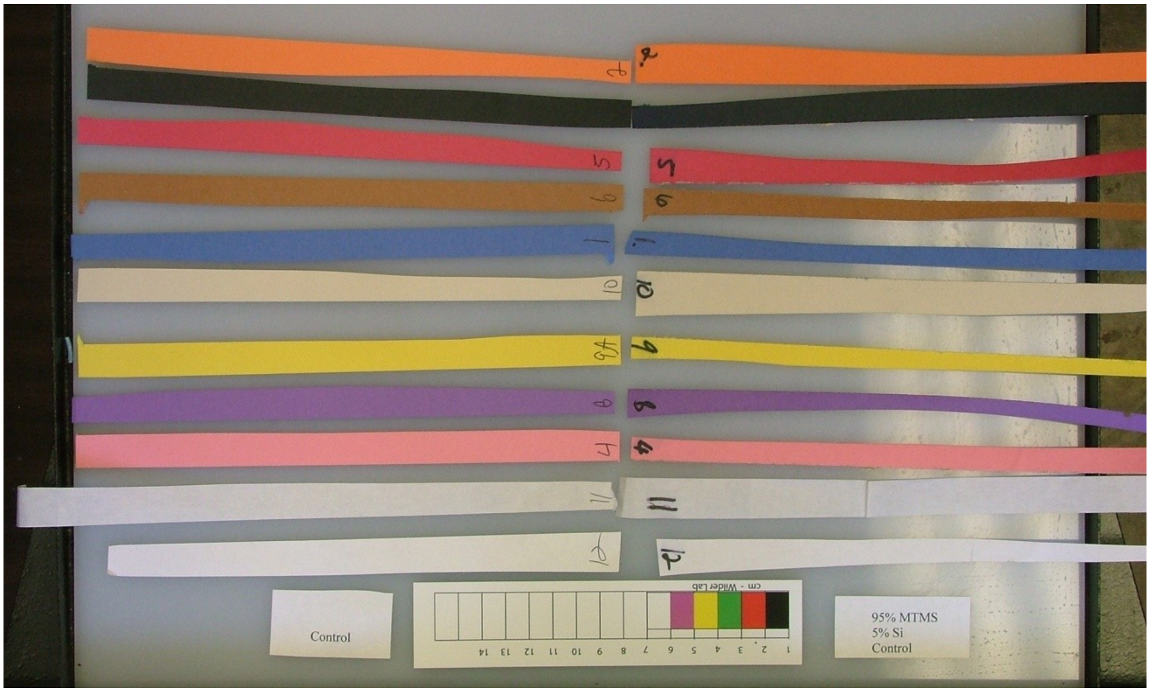
The printer paper and the butcher paper have become translucent.

20% MTMS + 80% Si

Flexibility: Compared to the control, it is nearly the same
Texture: Compared to the control, it feels thicker and slick and waxy
Color: Compared to the control, it is darker, and has a translucent quality
Creasing: Compared to the control, you can see and feel the crease
Ink marks: none
Tearing: Compared to the control, it tears easier, but not as easy as others

While the construction paper has become darker, the butcher paper and printer paper have become translucent.

95% MTMS + 5% Si



Flexibility: Compared to the control, it is the same
Texture: Compared to the control, it is the same
Color: Compared to the control, it is the same
Creasing: Compared to the control, it is the same
Ink marks: None
Tearing: Compared to the control, it is the same
This solution provided the best overall result, as the paper appears the same as the control and the creasing is not an issue.

Conclusion: The first sample, 100% MTMS + 0% Si oil, provided good results, but the paper was made stiffer, so that the original crease could still be felt. The upside is that the paper was made stronger.
It became apparent that all of the samples that had 20% Si oil or more took on a translucent quality and were easier to tear. The crease could be felt. This is the result of the compression of the fibers before it was placed into solution. These solutions did nothing to strengthen the paper.
The last comparison, 95% MTMS + 5% Si oil provided the best results. Not only did not of the qualities of the paper change, the creased area was not apparent after treatment. The final result is that the optimum results were achieved using this solution.

Experiment 2

Hypothesis: By experimenting on paper that has undergone similar weathering, it will be possible to predict the response of similar artifactual paper.

Problem: In the bonfire paper collection, several artifacts have become deteriorated as a result of being exposed to sun, wind, and rain, from being left outside as a part of a memorial to the Aggies who died or were injured when the bonfire collapsed. In order to establish a conservation treatment for the artifact, it will be attempted to replicate the kind of conditions that those artifacts endured. It is known that the paper underwent:

Bleaching from sun exposure
Deterioration from rain
Deterioration from aeolean effects
No freezing conditions are believed to have contributed to the deterioration

After documenting each sheet of paper, it was taped to the outside of a window and allowed to naturally weather. After being left outside for two weeks in the spring, the paper deterioration is similar to that the artifacts would have suffered in the fall season in Texas. Since some of the paper is known to have had both water-based ink and pencil used upon it, these will be placed on each as well.

Materials:
Controls and damaged heavy weight construction paper, printer paper, and butcher paper
MTMS (methyltrimethyloxysilane)
Si oil
Newspaper for blotting

Two sheets of each color have been selected. Each paper will have a control placed aside of similar color. The controls, treated and untreated, were established in experiment 1 presented before. Each paper will be given a catalog number, written in Sharpie®. Photos of each have been taken.

1. Blue
2. orange
4. pink
5. red
6. brown
7. black
8. purple
9. yellow
10. manila

Additionally, butcher paper (11.) and printer paper (12.) was selected, but the before photos are unavailable.

On each experimental sheet of paper, two wavy lines of pencil have been placed. A wavy line of blue, red and black water-based marker have been placed on there as well (vertically). A straight line of Sharpie, permanent ink was also placed on them as well (horizontally). This has been done in order to observe the deterioration rate of these media.

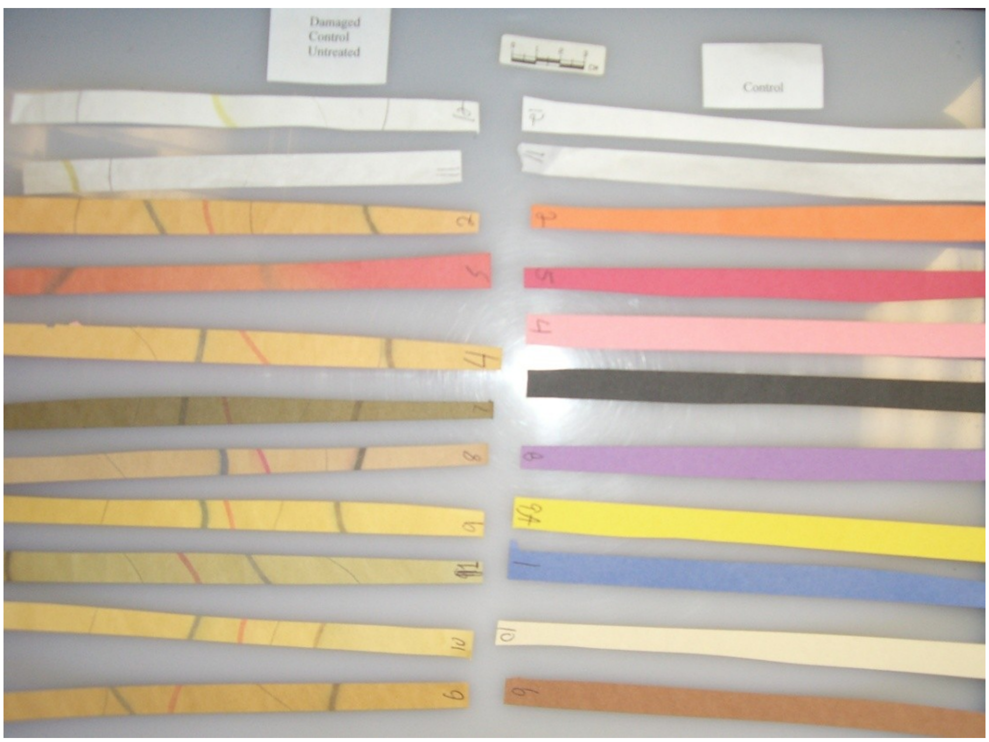
Procedure: Of both the control and the damaged, one of each color of paper has a strip cut from it to go into one of five different MTMS/Si oil solutions. The solutions are, by weight:

100% MTMS + 0% Si oil

0% MTMS + 100% Si oil
60% MTMS + 40% Si oil
20% MTMS + 80% Si oil
95% MTMS + 5% Si oil

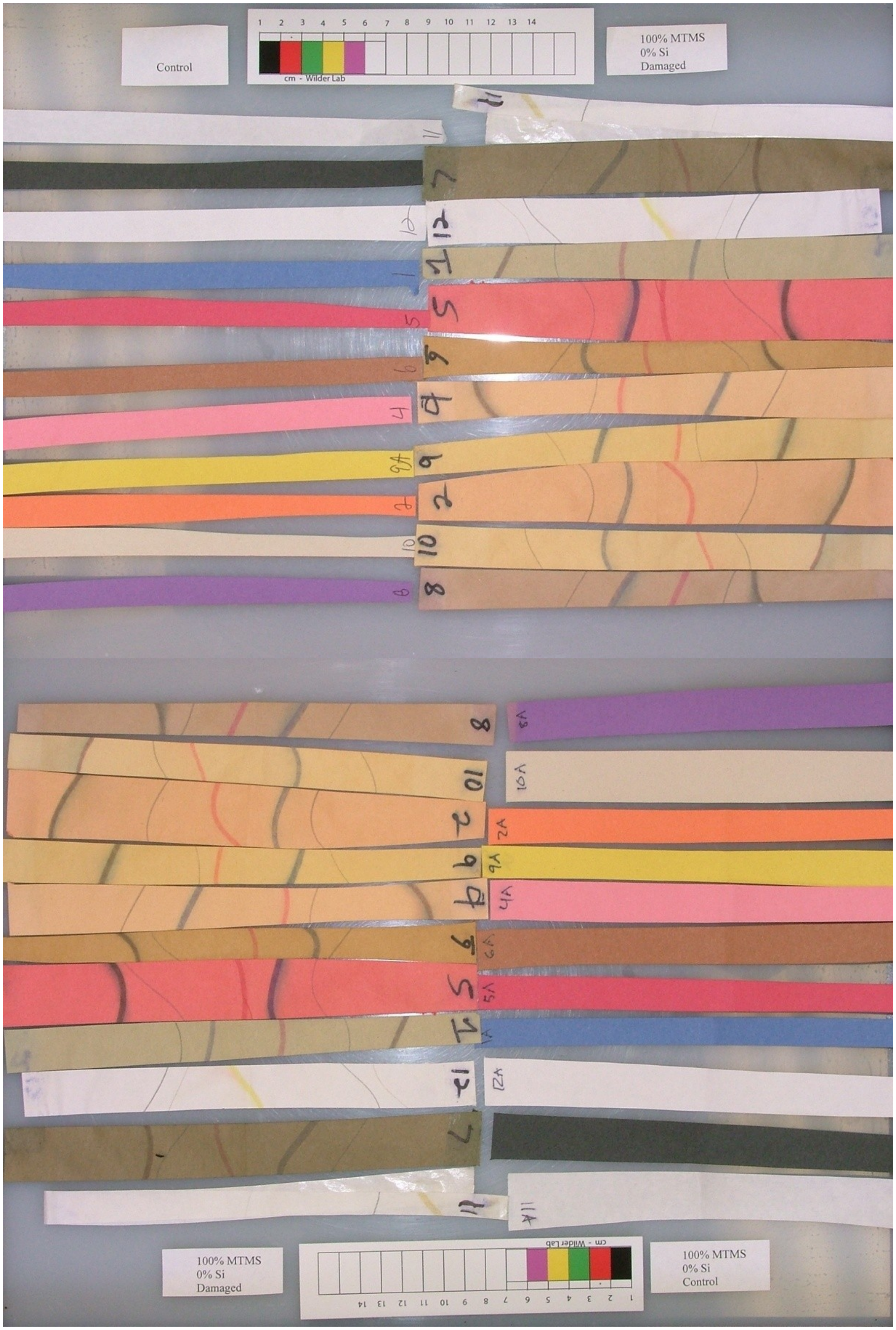
They remained in solution for a week. After that they were removed and blotted over a period of five months, to remove any residual treatment solutions. These are then compared to the control untreated and the control untreated damaged, and the damaged treated is also compared to the control treated. These were compared based upon flexibility, texture, color, creasing, ink marks, tearing, microscopically, and ESEM (later) on a five point scale (see spread sheet) and a written description.

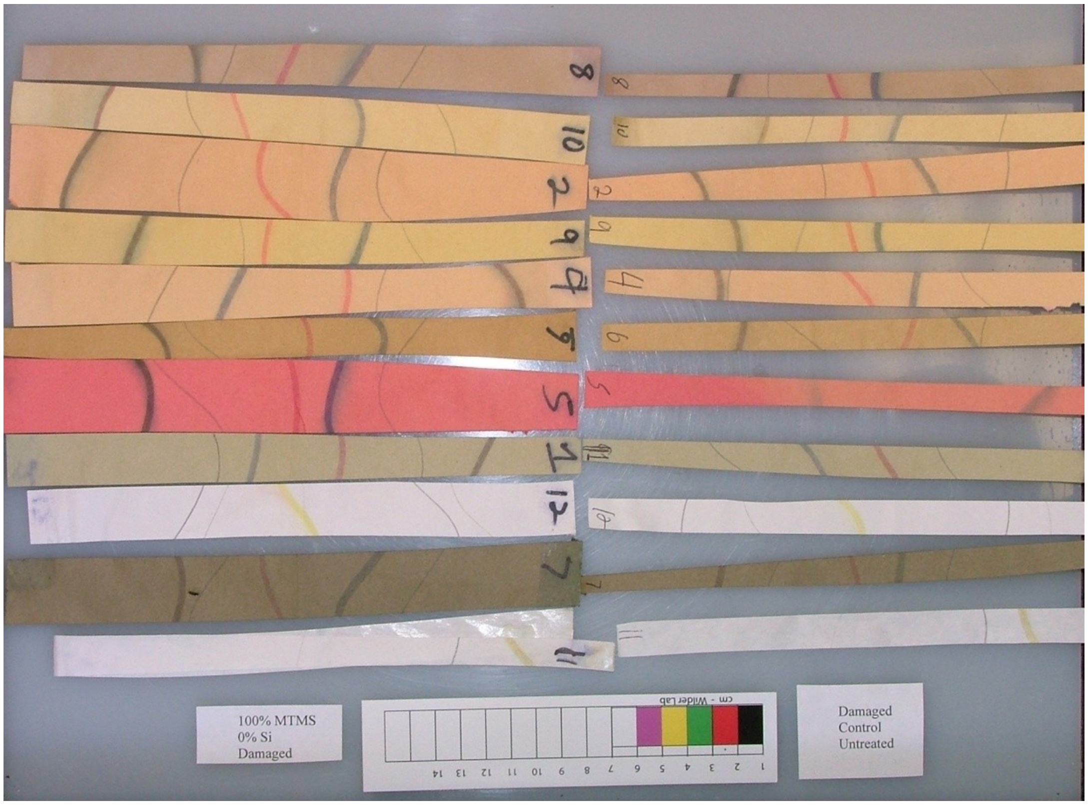
Data:
The first image compares the two control groups: the weathered control versus the original control.



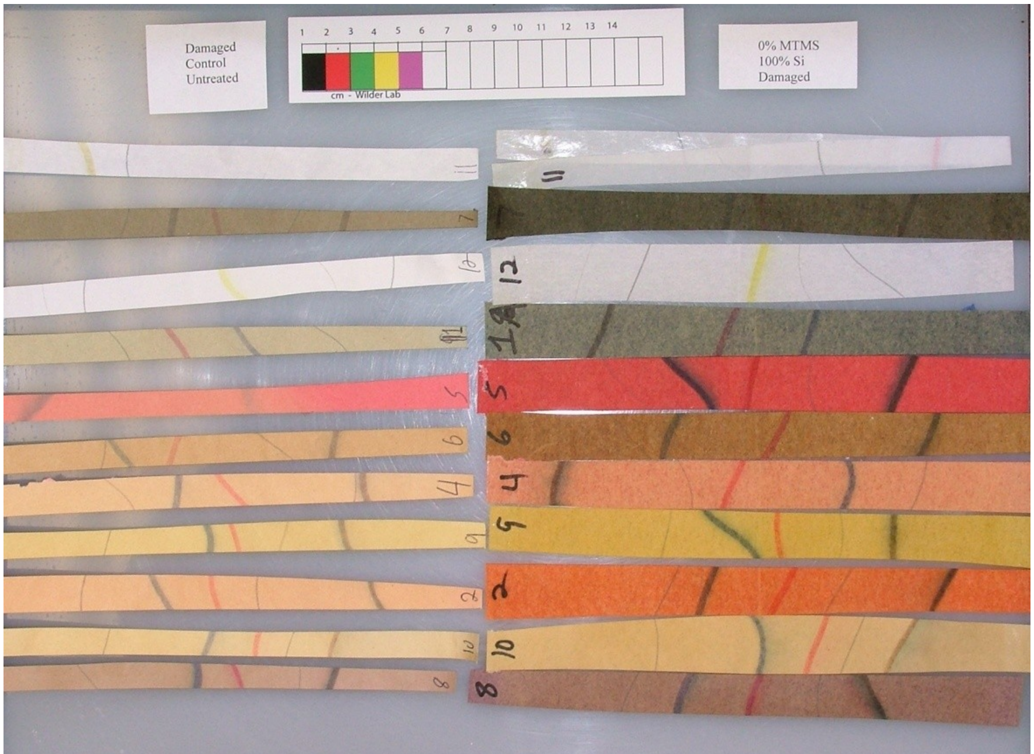
Damaged control vs contol

At this point, each of the treated damaged samples will be compared to the control, the treated control, and the damaged control through photographs. A discussion will follow.


Control
cm - Wilder Lab
100% MTMS
0% Si
Damaged
100% MTMS
0% Si
Damaged
100% MTMS
0% Si
Control

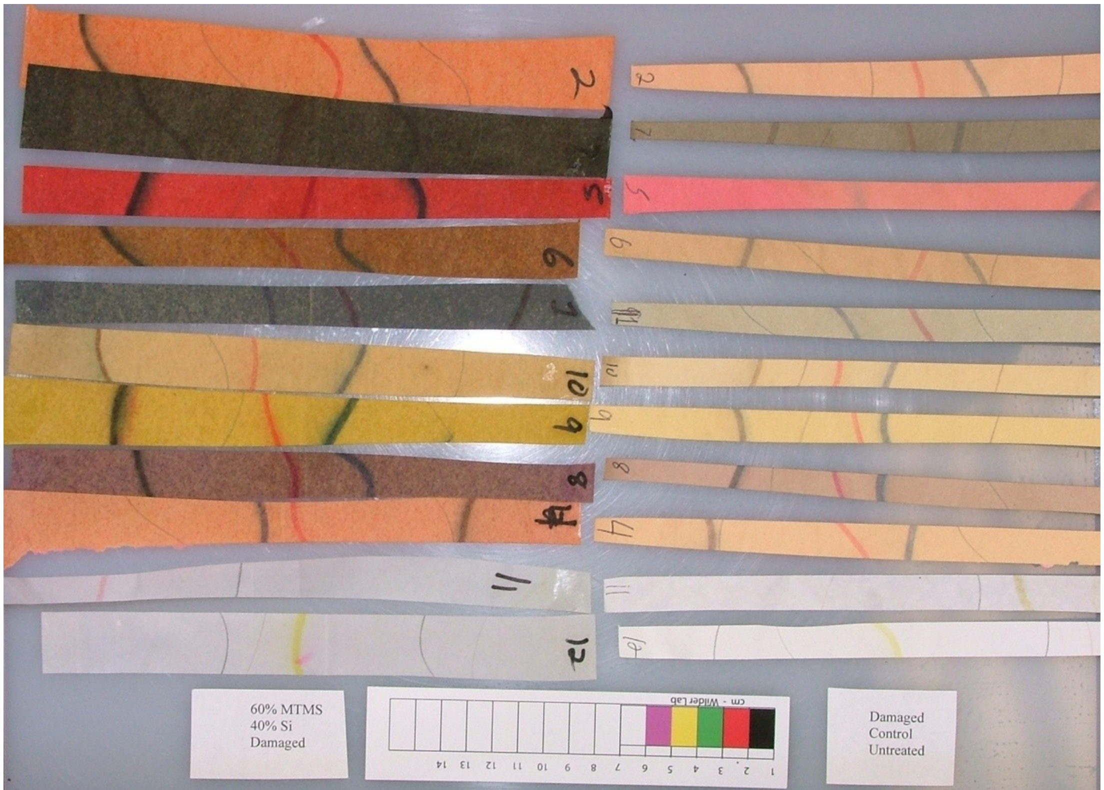


100% MTMS + 0% Si oil
Flexibility: Compared to the weathered control, it is more flexible
Texture: Compared to the weathered control, it is not as rough and does not feel as thick. This could be the result of the chemical or the blotting when wet, which would have smoothed out the cockling.
Color: Compared to the weathered control the color is the same
Creasing: Compared to the weathered control, you can see but not feel the crease
Ink marks: While all of the ink is faded, there is no bleed
Tearing: Compared to the weathered control, it tears about the same

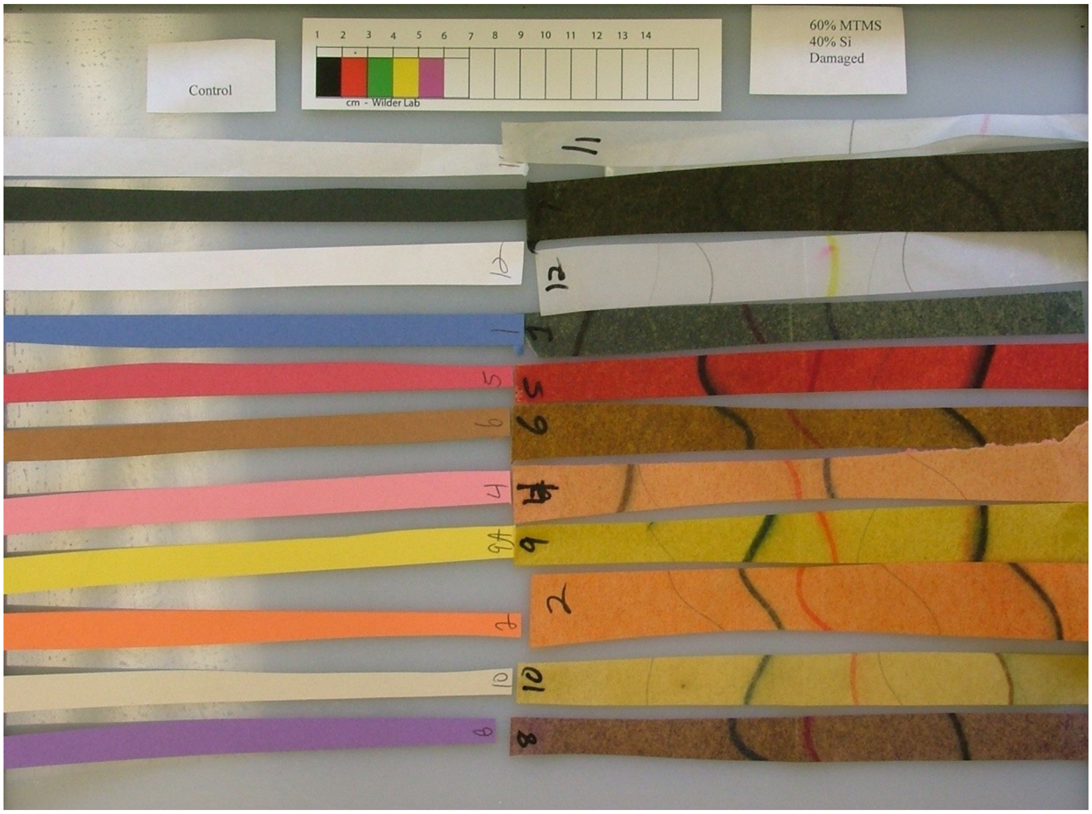

Damaged
Control
Untreated
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab
0% MTMS
100% Si
Damaged


Control
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab
0% MTMS
100% Si
Damaged

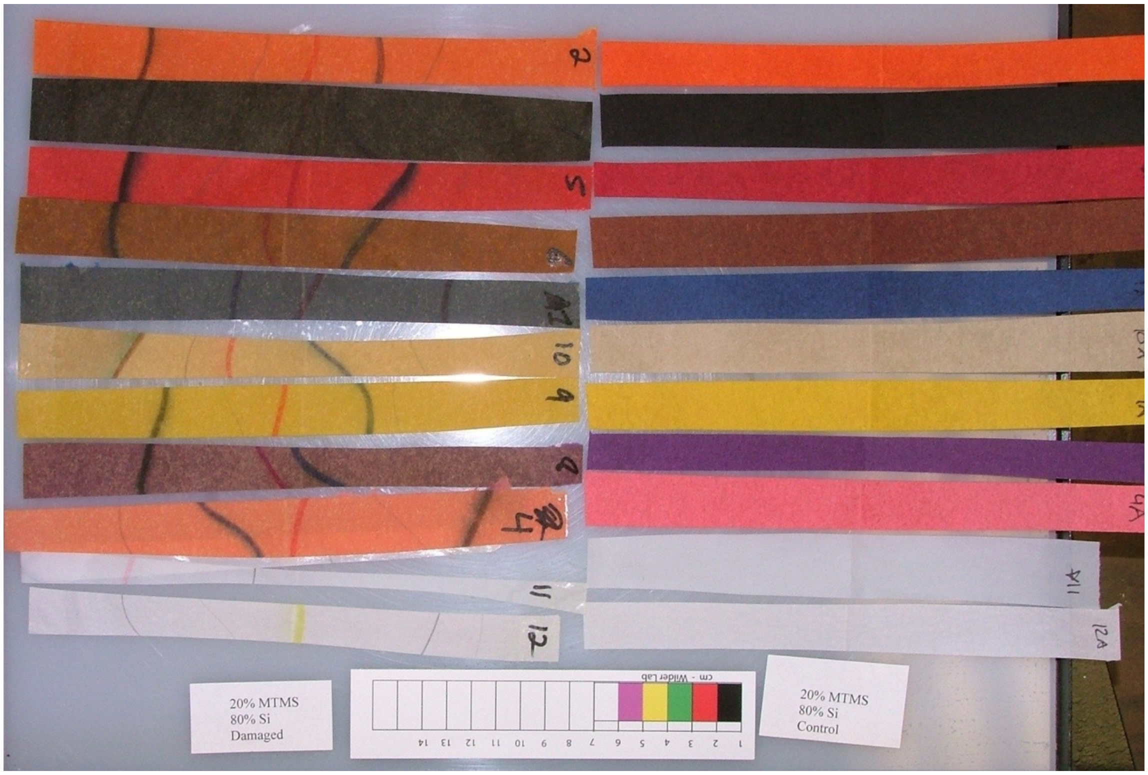
0%MTMS + 100% Si
Flexibility: Compared to the weathered control, it is more flexible
Texture: Compared to the weathered control, it is smooth, waxy almost oily.
Color: The color is brighter and more blue is seen, but it still is not that close to the control
Creasing: Compared to the weathered control, you can see and feel the crease
Ink marks: The ink seems more faded, but is isolated
Tearing: Compared to the weathered control, it tears more easily

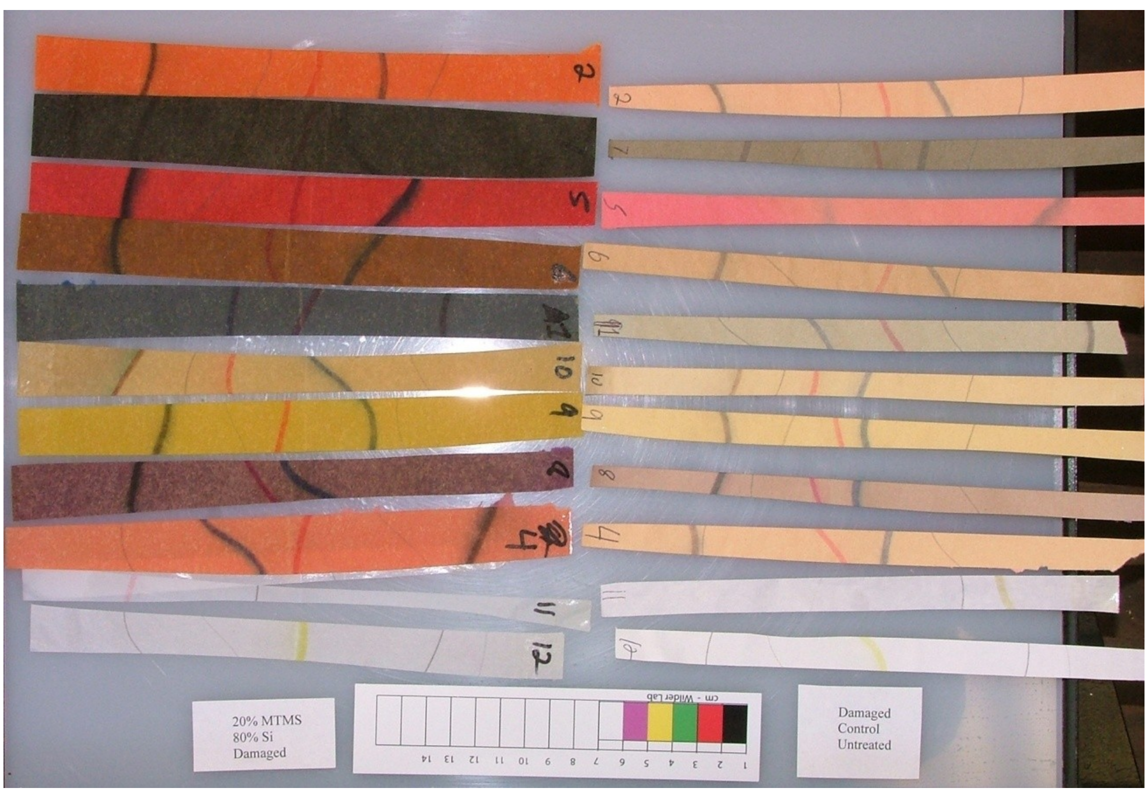

60% MTMS
40% Si
Damaged
cm - Wilder Lab
Damaged
Control
Untreated

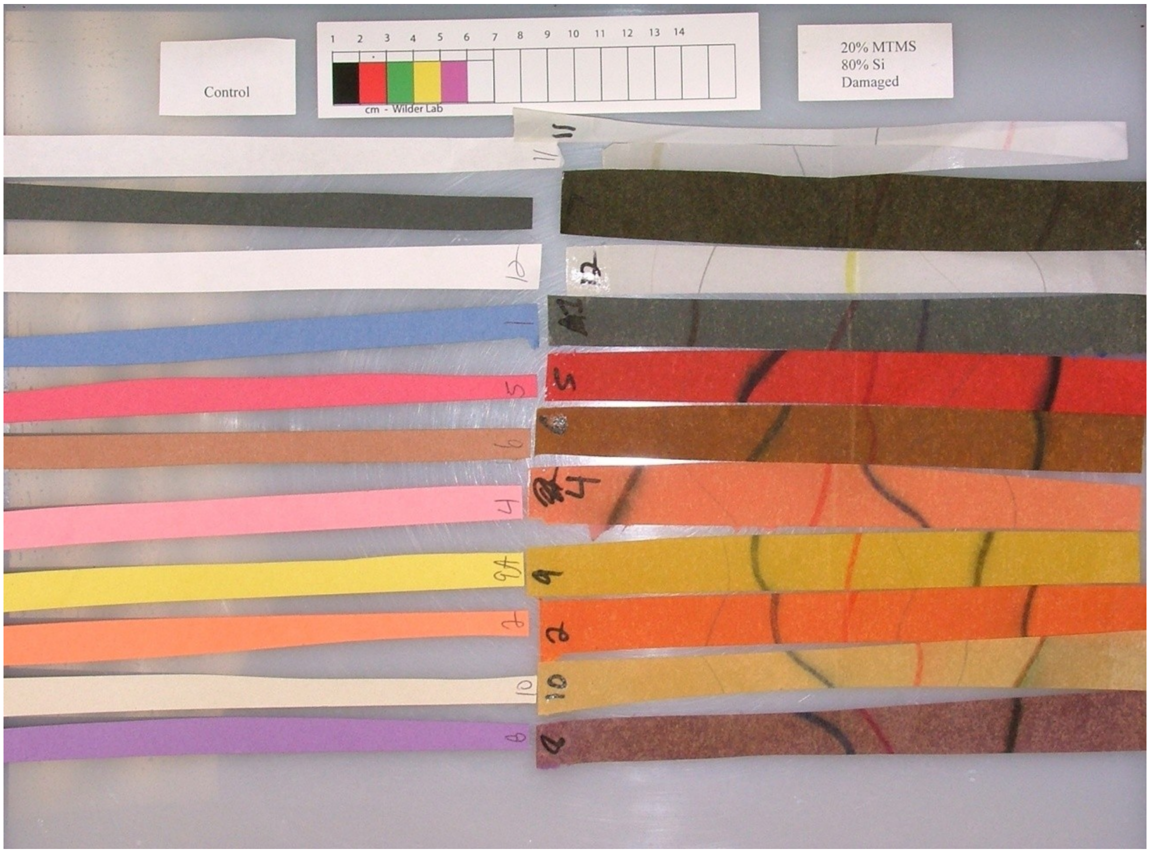

60% MTMS
40% Si
Damaged
cm - Wilder Lab
60% MTMS
40% Si
Control



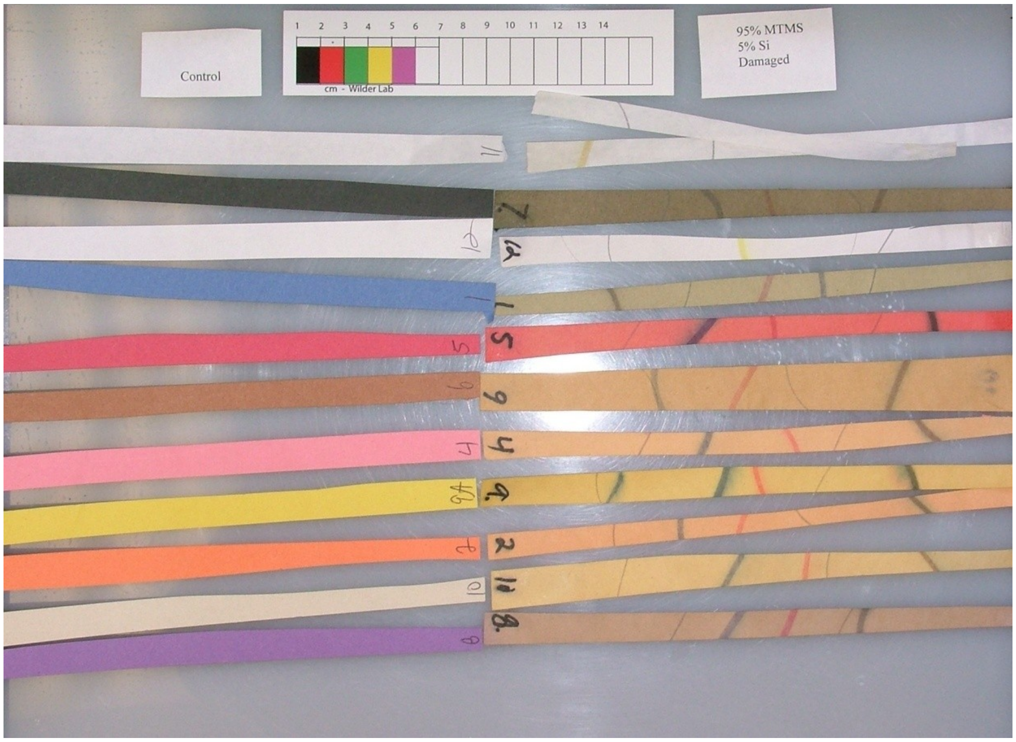
60% MTMS + 40% Si
Flexibility: Compared to the weathered control, it is more flexible
Texture: Compared to the weathered control, it is smooth and flat, but still too slick. This could be the result of the chemical or the blotting when wet, which would have smoothed out the cockling.
Color: The color is brighter and closer to the control in brightness, but still not the same; the fibers easily seen, but not as easily as seen in 100% Si.
Creasing: Compared to the weathered control, you can see but not feel the crease
Ink marks: while the control has no ink, the other ink is just faded
Tearing: Compared to the weathered control, it tears more easily

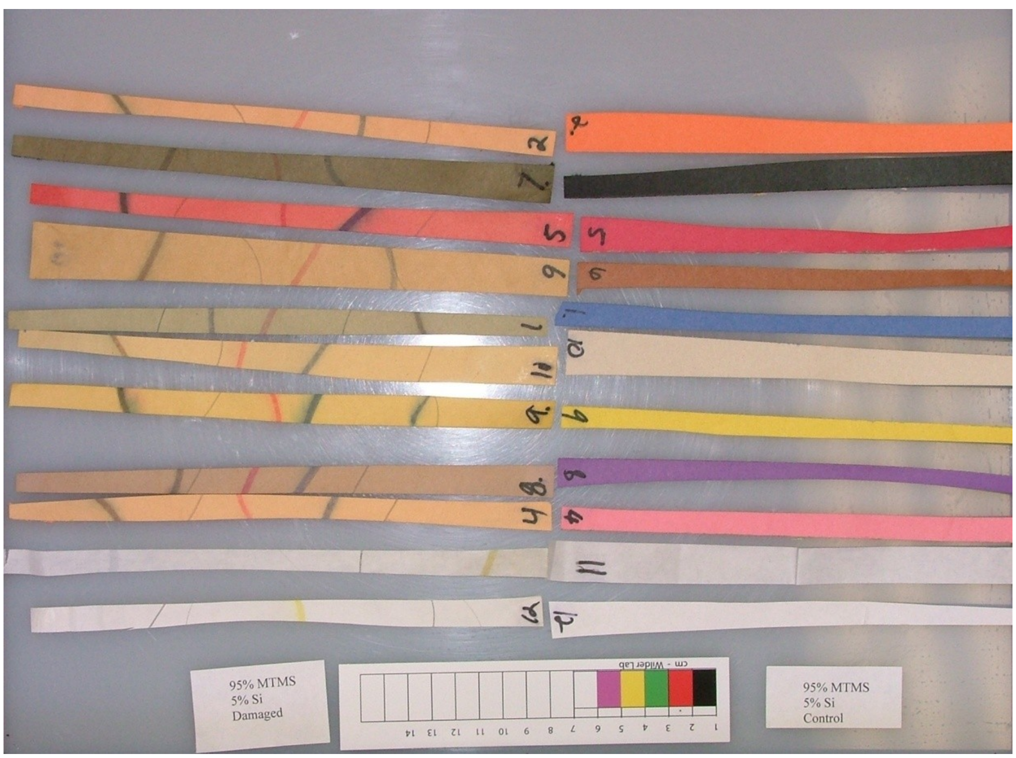

20% MTMS
80% Si
Damaged
20% MTMS
80% Si
Control

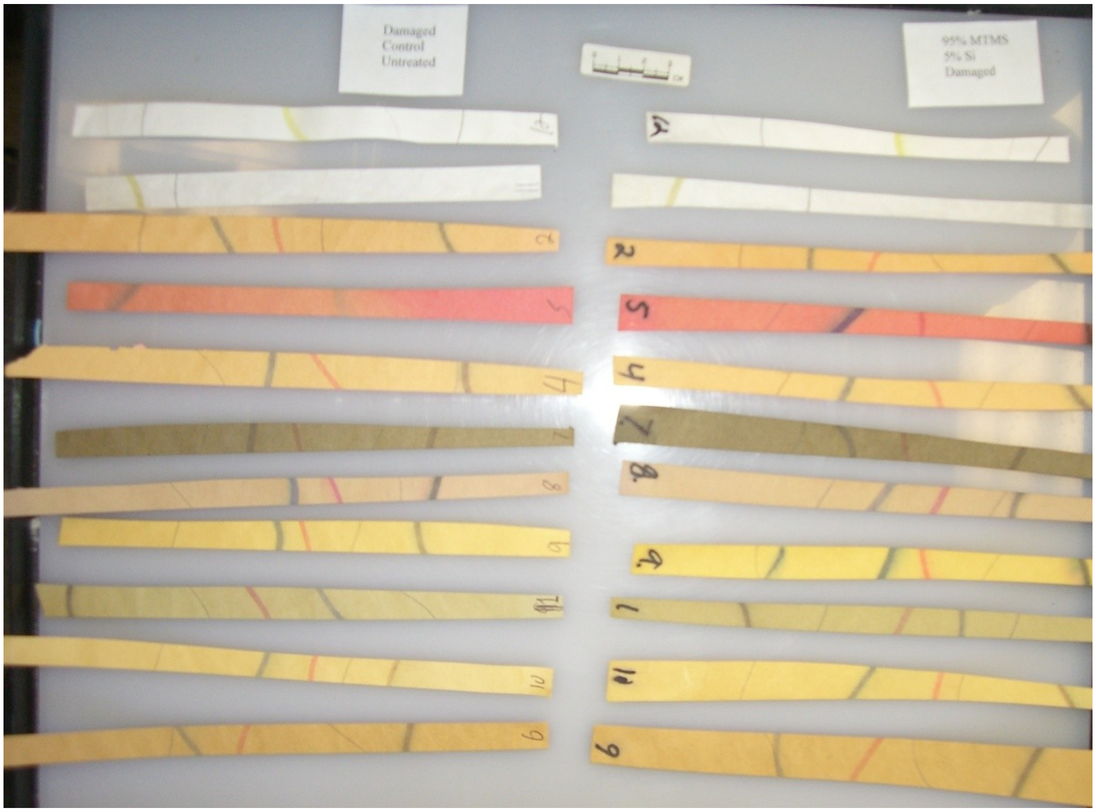

20% MTMS
80% Si
Damaged
Damaged
Control
Untreated



20% MTMS + 80% Si
Flexibility: Compared to the weathered control, it is more flexible
Texture: Compared to the weathered control, it is smooth, waxy and flat. This could be the result of the chemical or the blotting when wet, which would have smoothed out the cockling.
Color: The color is brighter and closer to the control in brightness, but still not the same; the fibers are more easily seen, but not as easy as seen in 100% Si.
Creasing: Compared to the weathered control, you can see and feel the crease
Ink marks: while the control has no ink, the other ink is just faded
Tearing: Compared to the weathered control, it tears more easily


Control
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab
95% MTMS
5% Si
Damaged


95% MTMS
5% Si
Damaged
cm - Wilder Lab
1 2 3 4 5 6 7 8 9 10 11 12 13 14
95% MTMS
5% Si
Control



95% MTMS + 5% Si oil
Flexibility: Compared to the weathered control, it is more flexible
Texture: Compared to the weathered control, it is not as rough and does not feel as thick. This could be the result of the chemical or the blotting when wet, which would have smoothed out the cockling.
Color: Compared to the weathered control the color is the same
Creasing: Compared to the weathered control, you can see but not feel the crease
Ink marks: While all of the ink is faded, there is no bleed
Tearing: Compared to the weathered control, it tears about the same

Conclusion: Based upon all of the results of which of the treated papers retained as much of the original traits of the controls, it was decided that the 95% MTMS and 5% Si oil is the best treatment for weathered construction paper. It was the most flexible, provided the best texture, retained the color of the control the best, handled post treatment creasing the best, did not corrupt or diminish ink lines, and did not tear more easily than the controls. While the 100% MTMS treated papers performed similarly, the small addition of Si oil may be beneficial in the long run. It is thought that this treatment will be best used on the construction paper in the Bonfire collection.

Experiment 3.

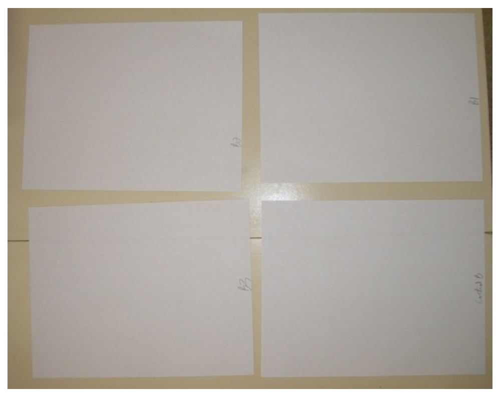
Accelerated aging of paper.

Hypothesis: Paper treated with 95% MTMS + 5% Si oil will withstand accelerated aging better than non-treated paper.

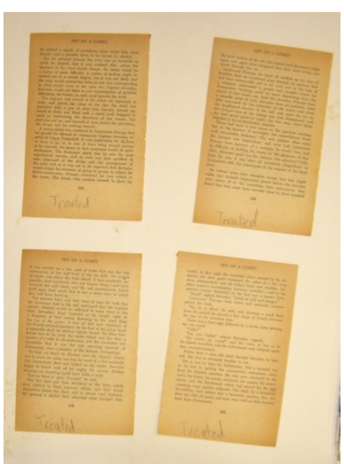
Materials:

- Paper for experiment
  - Whatman #1: treated and control
  - Printer paper: Treated and control
- Silane solution 95% MTMS and 5% Si oil by weight
- Oven 90° Celsius
- Relative humidity approx 50-90%

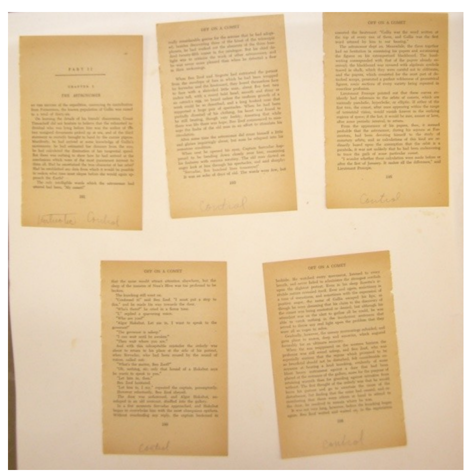
Procedure: Create solution. Place each individual paper into solution. Remove and place on blotter paper. Allow to dry for ½ hour.



Treated paper on top, untreated on the bottom.



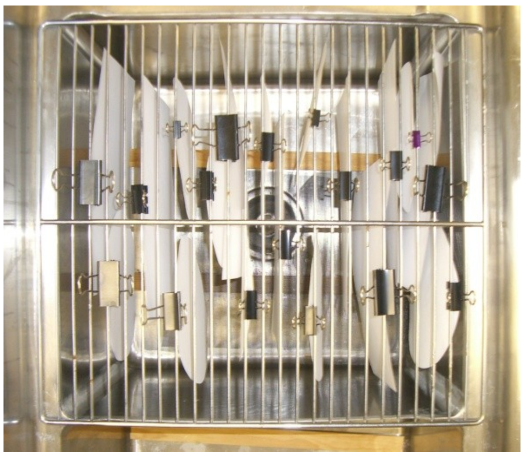
Treated



Untreated

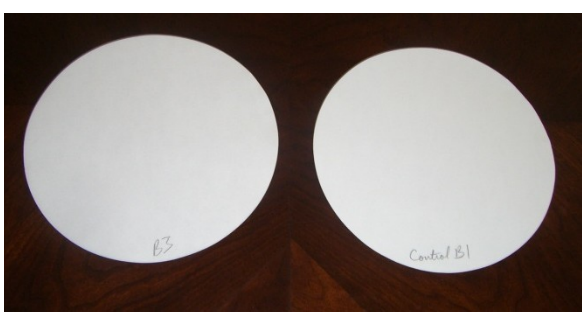
Four treated pages of *Off on a Comet* treated with $CaCO3$ MTMS spray and five untreated pages were added to the oven. These were aged for 5 days.

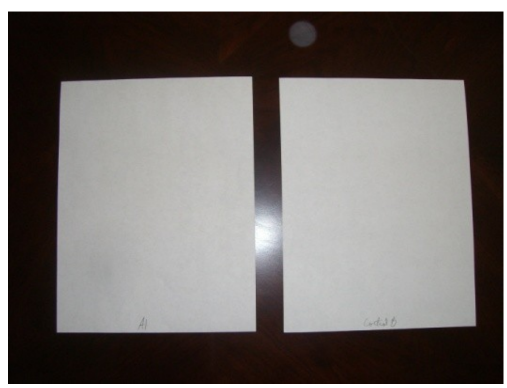
Both the controls and treated into oven hanging by clips. They were heated with water in oven for 5 days and 15 days for two batches of results.

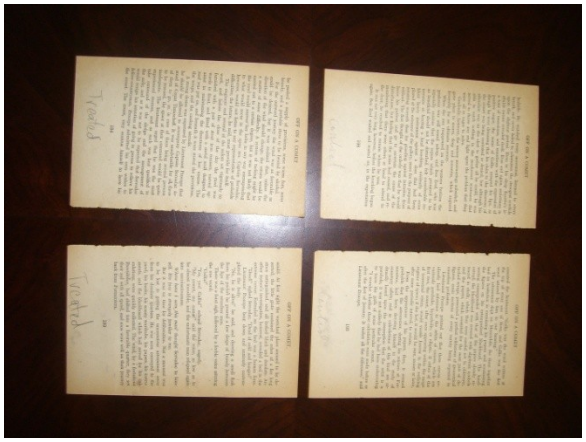


Data:
Both batches went back into the lab oven at 90° with a jar of water to add humidity to the oven, replaced once a day. They remained in the oven for 9 more days, for a total of 15 days.

After 15 days, the Whatman paper and the printer paper showed no change. After 5 days the book paper showed no change.







Paper after accelerated aging. The treated on left, untreated on right in all photos.

Conclusion: The amount of time in the oven should have equated to over 500+ years of aging. Since there was no change, it seems all of the paper is more stable than previously believed. Accelerated aging is a controversial technique used to evaluate the endurance of paper or treatments. This experiment did not offer positive or negative results, but demonstrated that the test is not a valid measurement of aging in real-world conditions.

Experiment 4.

Hypothesis: there are several treatments for waterlogged paper, none of which add additional strength to an already weakened paper. Passivation polymers will add strength to previously waterlogged paper, thereby conserving it.

Materials:

Ten pages of Printer paper stapled together cut into half to emulate a book
Amazing Stories book
Vacuum freeze dryer
Water
Blotters
95% MTMS + 5% Si oil

Procedure: Put controls (not waterlogged) aside. Create waterlogged paper samples by placing paper in a plastic bin, and cover with water. Let sit for 48 hours. Then, remove paper for various treatments.

A. treat the paper.
1. Air dry
2. Vacuum freeze-dry
3. Dehydrate and treat with passivation polymers
4. Vacuum freeze-dry and treat with passivation polymers

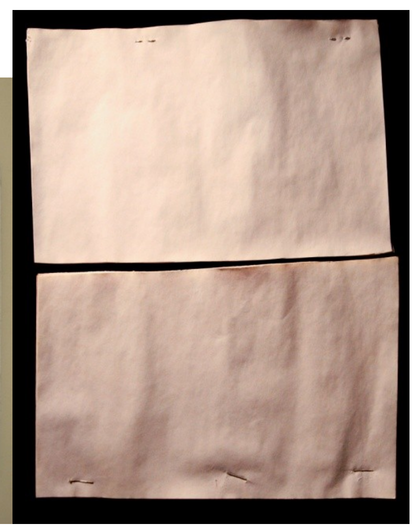
B. Compare to all controls and each other

The water in the tub became yellow, likely as a result of the acids washing out of the paperback included in the water or the yellow ink on the cover being water soluble. This emulates the conditions that might arise as a result of flooding, where mixed materials share the same environment.

Data:

1. Air dried

Before

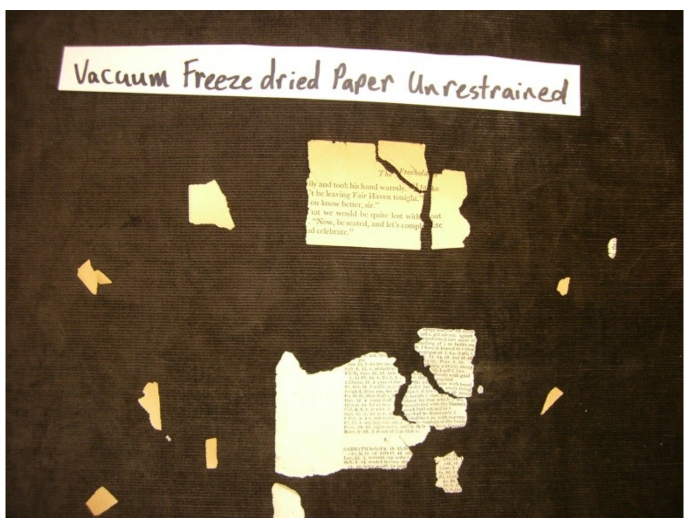


After

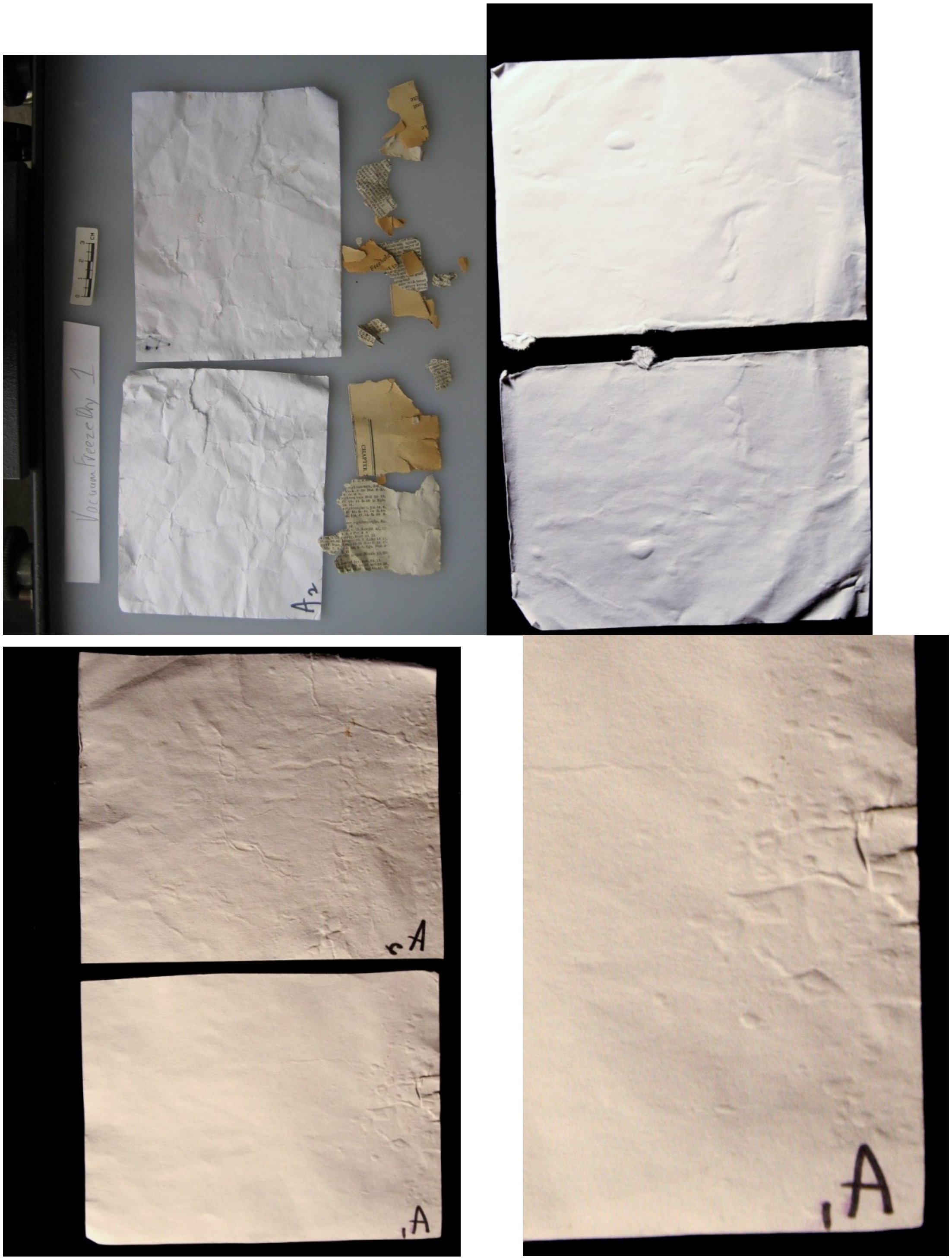
The paper was flat prior to allowing it to air dry. It took about 36 hours to completely dry. The dried paper is cockled and bent. It would be a lot worse, if the staples had not been restraining it from continuing to pull away from the other pages. It is expected that this paper is weaker than paper that would have been treated with passivation polymers.

2. Vacuum Freeze dry
Paper to be submitted to the vacuum freeze drier has been fitted into polyester mesh packets to compress the paper to maintain its shape.

Image of the vacuum freeze dryer and the polyester mess packets before being placed into the freeze dryer.

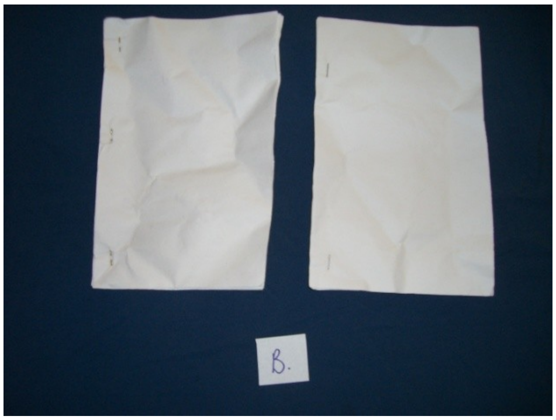


In past experiments with vacuum freeze drying paper, it was found that if the paper was not constrained, it was damaged or literally blown to bits or other deformation took place.



The printer paper that underwent vacuum freeze drying was stronger, but still suffered from the forces of drying. Note the "bubbles" that are believed to have been formed by irregular drying in the past examples of unrestrained drying.

Two different samples were submitted to vacuum freeze drying. The vacuum freeze drying took 32 hours to complete. When the paper came out of the dryer, it was removed from the mesh bags. The paper is creased and cockled to some degree.



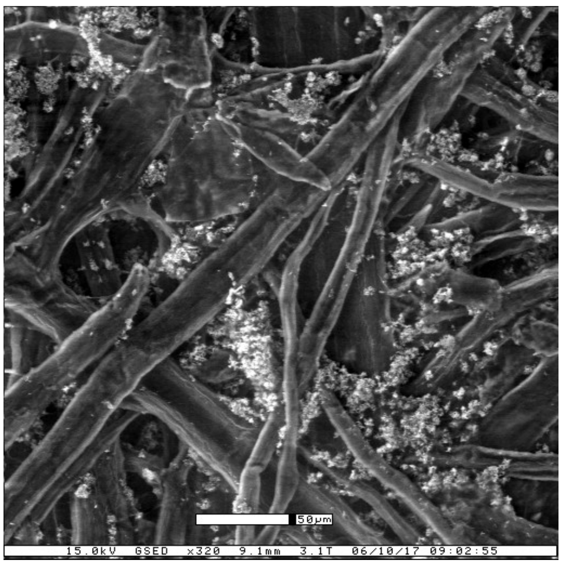
Post vacuum freeze dried paper

After vacuum freeze drying the paper felt more rough, as if the fibers have become loose, but this also makes the paper seem to be more soft to the touch and not as stiff when compared to the control. The first set of pages was analyzed and put aside. The second sample was put into a solution of 95% MTMS and 5% Si oil. The second sample felt as soft as the first before solution, but after treatment it did not feel as soft. The ten sheets together seemed more compact than the sheets in the first sample. Neither sample felt as compact or smooth as the control.

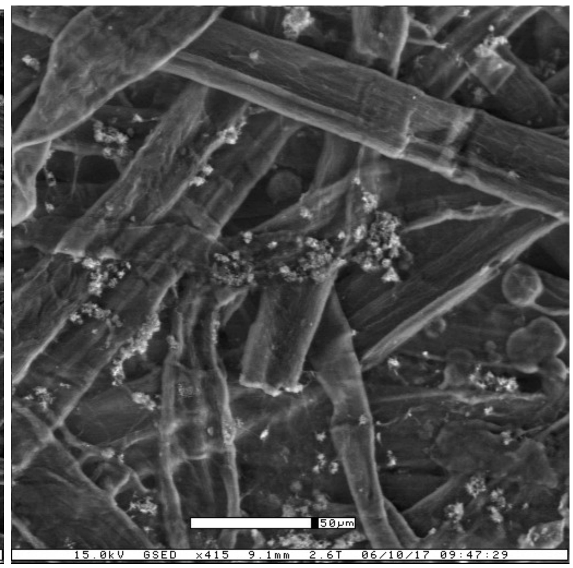
Post vacuum freeze dried paper after treatment with passivation polymers

Passivation Polymer treatment

The paper to be submitted to Passivation polymer treatment has been fitted into polyester mesh packets, similar to the ones used in the freeze drying experiment. This was done to maintain consistency between the two. The paper needed to be dehydrated prior being placed into the solution. The baths began with a mixture of 25% ethanol and 75% water increasing in 25% increments to 100% ethanol. These were followed by bathes of ethanol and acetone, beginning with 25% acetone and 75% ethanol increasing in 25% increments to 100% acetone. The baths were changed every 20 minutes. It was then placed into a polymer solution of 95% MTMS and 5% Si oil (SDF 1) and left overnight.

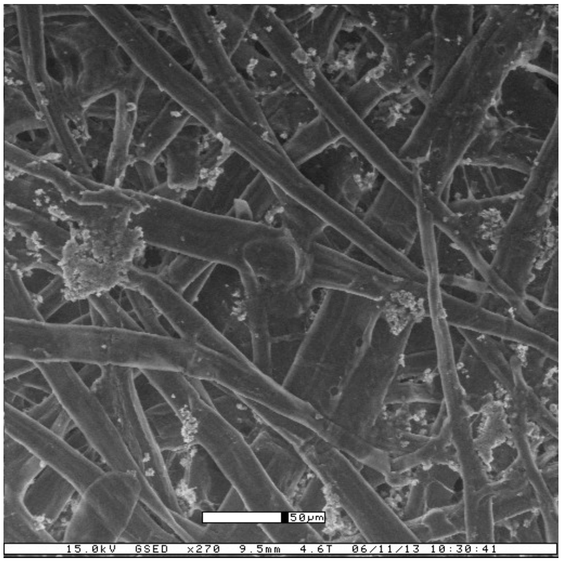


Printer paper control ESEM photo

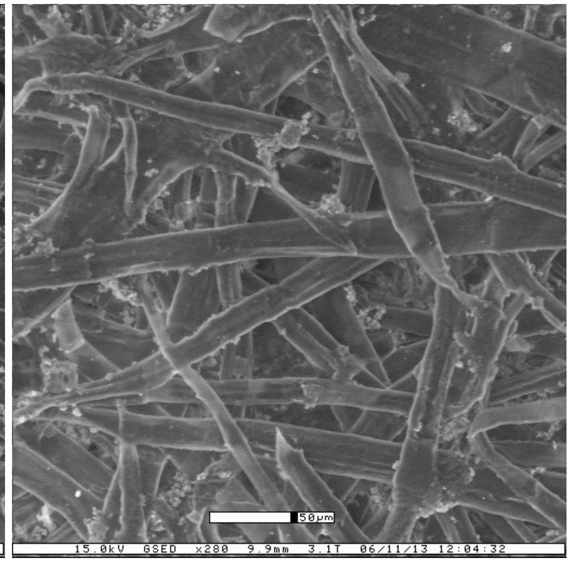


Printer paper after waterlogging

Note the loss of filler material and further stress on the fibers after waterlogging. They appear more broken and have “hairs” of fibrils detached from the individual fibers. The fibers look more compressed as well.

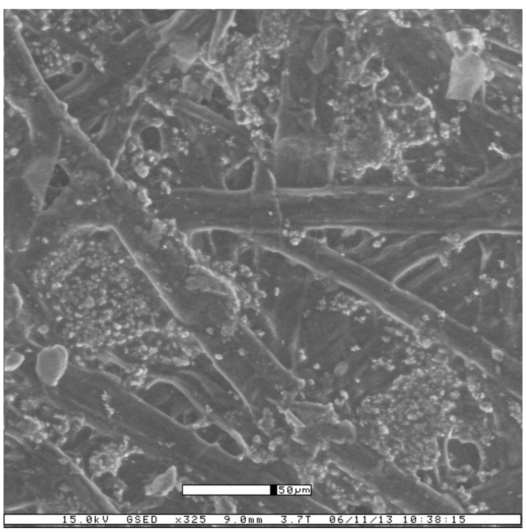


Control printer paper after 95% MTMS.

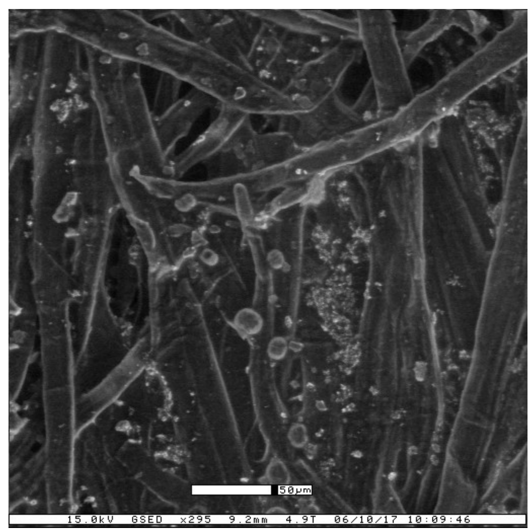


Printer paper waterlogged, dried and treated with 95% MTMS.

The paper has loss filers in the second photo, but the fibers look well-defined and strong.

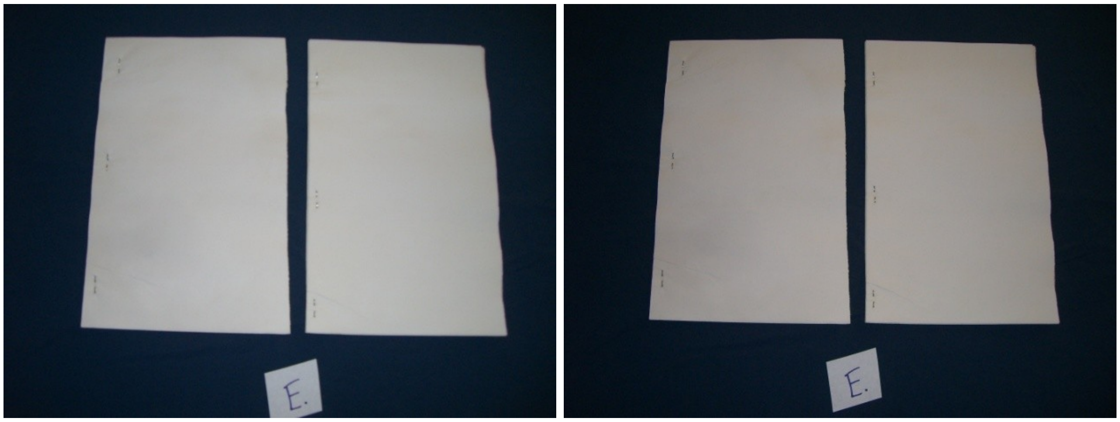


Control printer paper after 100% Si Oil



Printer paper Printer paper waterlogged, dried and treated with 100% Si Oil

In both of these photos, the Si oil seems to have overwhelmed the fibers and the matrix is not seen as easily.



Paper after waterlogging and treatment with passivation polymers.

After dehydration, the papers felt stiff, but that is to be expected. After polymer treatment, the paper felt very similar to the control. With the exception of a little warping, probably the result of the relaxing of the fibers during the waterlogging, this method provided results that most closely resembled the control.

Conclusion: The air dried sample does not look good because it is warped and cockled. Paper that was vacuum freeze dried feels softer and weaker. After treatment with passivation polymers, it not feel as soft and was more compact. The wet paper that was submitted to organic solvent for drying and then placed into a Passivation polymer solution felt and responded very similar to the control. Its features were more similar to the control than either the air dried paper or the vacuum freeze dried paper.

Experiment 5.

Purpose: A series of papers were wetted and dried in various ways, the effects of the drying methods are assessed through ultrasonic testing and MIT folds.

Background:

Ultrasonic instruments measure the propagation of sound directionally through (out of plane) or along (in-plane) a sheet. The directional speed of sound squared divided by the density of the material is directly related to the elastic constants of the paper pertaining to that mode and direction of sound propagation. In the cases tested, sound waves may be longitudinal or shear waves depending on the selected situation.

The following relies heavily on Habeger's chapter in Handbook of Physical Testing of Paper (2001).[1] An orthotropic material is defined as having three mutually perpendicular planes of symmetry. In the case of paper and paperboard, these would be defined as the machine direction (MD), the cross direction (CD), and the thickness of the sheet (ZD). The response of the material to a particular stress can be described in terms of nine orthotropic constants, shown in equation 1.

$$\begin{vmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{23}\\ \sigma_{13}\\ \sigma_{12}\end{vmatrix} = \begin{vmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0\\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0\\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0\\ 0 & 0 & 0 & 2C_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & 2C_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & 2C_{66}\end{vmatrix} \begin{vmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ \varepsilon_{23}\\ \varepsilon_{13}\\ \varepsilon_{12}\end{vmatrix}$$

When performing ultrasonic tests on the paper, this matrix can be reduced by making certain assumptions. If the surfaces of the sheet are unrestrained, then the stresses there must be zero. This makes σ_{33}, σ_{13}, and σ_{23} all zero and converts the stiffness matrix to:

$$\begin{vmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{12}\end{vmatrix} = \begin{vmatrix} C_{11} & C_{12} & 0\\ C_{12} & C_{22} & 0\\ 0 & 0 & 2C_{66}\end{vmatrix} \begin{vmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{12}\end{vmatrix}$$

The problem is then to figure out what the elastic moduli are by ultrasonic means. This can be done by relating the stiffness of a viscoelastic sheet to the square of the velocity with the following set of equations:

$$C_{11} = \rho \cdot c_{Lx}^{\ 2}$$
$$C_{22} = \rho \cdot c_{Ly}^{\ 2}$$
$$C_{66} = \rho \cdot c_{Sx-y}^{\ 2}$$
$$C_{12} = \left\{ \left[2\rho \cdot c_{S-45}^{\ 2} - \tfrac{1}{2}(C_{11} + C_{22}) - C_{66}\right]^2 - \tfrac{1}{4}(C_{11} - C_{22})^2 \right\}^{\frac{1}{2}} - C_{66}$$

where ρ is the density of the sheet, and c is the velocity of the wave. The subscript *Lx* denotes a longitudinal wave polarized and propagated down the MD, *Ly* denotes the same in the CD, *Sx-y* denotes a shear wave polarized in the MD, but propagated in the CD (or vice versa), and *S-45* denotes a shear wave polarized at 45° with respect to the MD, but propagated at -45° off the MD.[2]

The Poisson ratios can be determined from these four equations and the elastic constants can be calculated as:

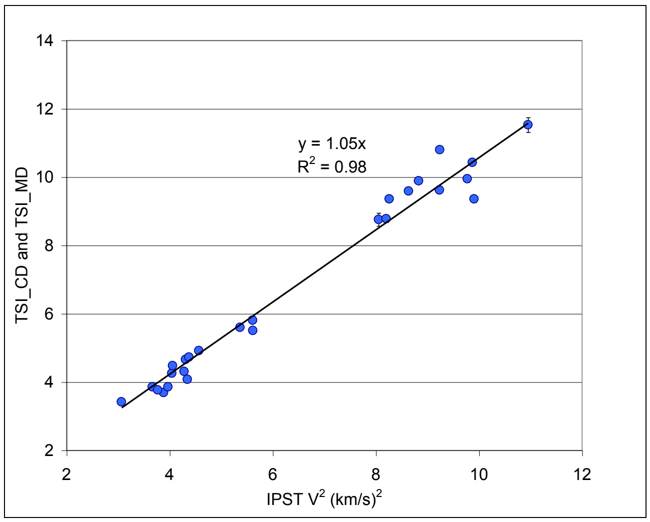
$$E_{11} = C_{11}(1 - \nu_{12}\nu_{21})$$
$$E_{22} = C_{22}(1 - \nu_{12}\nu_{21})$$
$$G_{12} = C_{66}$$

When out-of-plane measurements are available, three other constants can be determined:

$$C_{33} = \rho \cdot c_{Lz}^{\ 2}$$
$$C_{44} = \rho \cdot c_{Sy-z}^{\ 2}$$
$$C_{55} = \rho \cdot c_{Sx-z}^{\ 2}$$

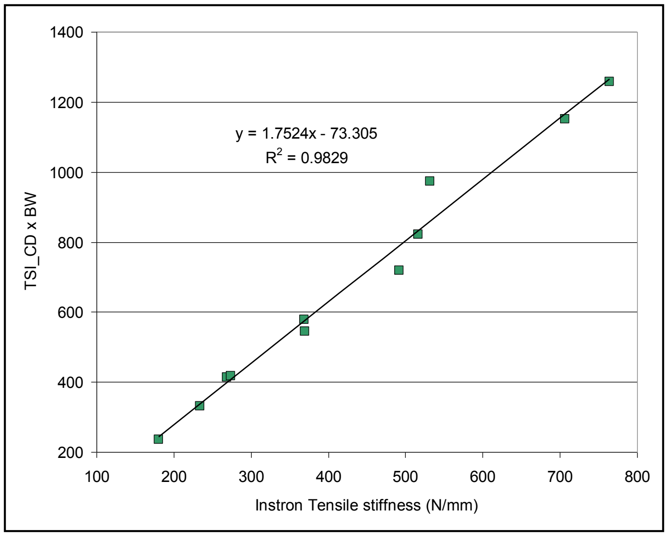
Ultrasonic measurements offer a quick convenient replacement for many mechanical measurements and are suggested here for the current purpose. Utilizing TSO or other sonically based stiffness data for other than orientation is an additional opportunity not realized in many installations. The correspondence between ultrasonic and mechanical measurements requires to be established since ultrasonic results are equipment specific. The IPST in-plane robot based ultrasonic measurement developed in the 1980's is based on a paired difference method which despite being comparatively time consuming, excludes artifacts that are introduced through electronic delays, sample-transducer coupling, signal processing and other details.

Accordingly, measurements of the specific stiffness V^2 from the legacy IPST instrument were compared with *TSI_CD* and *TSI_MD* values produced from a TSO instrument using a variety of commercial paper and plastic sheet samples with a wide range of basis weights. Figure 2 shows that *TSI_CD* and *TSI_MD* values correlate with IPST V^2 $(km/s)^2$ and are about 5% higher. The correlation requires the TSO instrument to be calibrated using its supplied Mylar laminated sheet.



Comparison of TSI output values and corresponding measurements of the IPST ultrasonic in-plane shown on graph.

Comparison of *TS_CD x β* (TSI_CD * basis weight) was made with the tensile stiffness $E_{CD}t$ (CD modulus times soft platen caliper) measured on the same selected paper set using T 494 tensile tests on an Instron testing machine model 1122 using Series IX software. Results shown in Figure 3 indicate that *TSI_CD x β* is larger than the mechanically measured equivalent tensile stiffness by 75 % which is an expected result consistent with previous comparisons of ultrasonic to mechanically measure physical properties.
The correlations of the TSO outputs with other measurements shown in Figures 2 and 3 provide the confidence to use TSO data.



Comparison of the TSI_CD x BW with tensile stiffness measured by mechanical testing shown in graph.

About IPST Paper Analysis Laboratory:

Paper Testing at IPST has over 2800 square feet of lab space dedicated to address any paper, board, and specialty product testing needs in areas of strength, optical, surface, and structural properties. In addition to conventional TAPPI method testing capabilities, the Paper Testing group can provide special services in the areas of environmental simulations and accelerated aging. Environmental chambers cover high and low temperature and humidity conditions. Unique capabilities include precision paper grinding or sheet splitting to produce specific thickness sections, score cracking of linerboards, needle abrasion testing to predict relative slitter and knife blade wear caused by abrasive components in both base sheet and coating materials, nondestructive in-plane and out-of-plane (Z-directional) ultrasonic testing, optical 3D Moiré surface topography for the measurement of curl or cockle. Our labs also offer the latest automated capabilities for real time hygroexpansive response measurements, and horizontal plane static and kinetic coefficient of friction determinations. Humidity and temperature conditions are monitored and tracked continually to ensure proper standard TAPPI conditions of 23°C and 50 % RH.

Data from the IPST Paper Analysis Laboratory have been validated through IPST participation in the Collaborative Testing Services Inc., and PAPRICAN Paper and Pulp Monitor programs. Internal checks by comparison with historic data on select samples and regular instrument calibrations using standards are standard procedures. This ensures that the equipment, methods and results are consistent with correct industry practice.

Method:

Sonisys OPUS 3-D – this instrument measures the out-of plane and in-plane elastic properties. Using a pair of shear transducers in parallel with a set of longitudinal transducers, the in-plane Poisson constants are determined so that the elastic moduli can be calculated. The soft platen caliper is measured in each measurement and the longitudinal out-of-plane velocity is used to calculate an out of plane modulus E_{33}. Measurements were taken across the banknote test sheets across the top and bottom either indiscreet interval positions or contiguously.

L&W TSO – this instrument uses a circular array of ultrasonic transducer to quickly determine the relative angle of the in-plane stiffness orientation. The outputs TSI indexes are MD and CD velocities squared which is also the specific stiffness in the principal in-plane directions. Measurements were taken at specific intervals across the test sheets.

MIT folds – this is a standard Tappi test where strips 15 mm wide and 160 mm long cut along the MD are placed in a MIT fold tester and suspended under tension as applied by a 1 kg weight to a tensioning spring. The number of cycles of the rocking anvil to break are recorded as a measure of the folding resistance.

Data:

Most measurements consist of at least 6 repeats or more whenever possible.

A comparison of significant differences between samples can be gleaned through comparison of the results with error bars representing the 95% confidence intervals of the results from repeated measurements for each sample. Data points with overlapping error bars are not considered statistically different. The following graphs are plots of the physical properties with the inclusion of 95% confidence interval error bars.

Summary of ultrasonic measurements and MIT folds, the stiffnesses have been converted by Poisson ratio measurement calculations, caliper and basis weight in table form.

Sample ID		Basis weight	Caliper	Density	ZD modulus	c.i.
		g/m^2	microns	kg/m^3	MPa	
A.	Air dried after Waterlogging	75.7	103.8	729	323.5	20.5
B.	Vacuum Freeze Dried	76.5	124.4	617.9	72.5	32.4
C.	Control	76.5	98.4	780.4	268.2	34.2
D.	Treated Control	79.9	99.2	806	296.1	5.5
E.	Waterlogged Treated	85.4	118.8	718.7	147.5	14.4
F.	Vacuum Treated	79.2	130.3	608.4	26.7	23

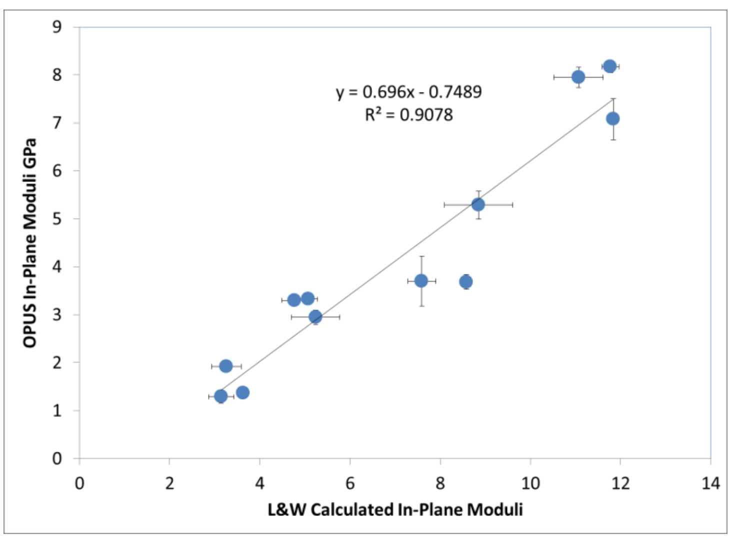
Sample ID	MD Modulus		CD Modulus		MIT folds		
	GPa	c.i.	GPa	c.i.		c.i.	
A.	7.077	0.328	2.95	0.149	122.6	36.0	58.1
B.	3.7	0.427	1.1292	0.148	19.6	6.9	11.2
C.	8.171	0.522	3.327	0.133	104.5	35.9	58
D.	7.951	0.129	3.302	0.129	62.7	11.1	17.9
E.	5.289	0.211	1.92	0.047	5.3	0.4	0.7
F.	3.684	0.291	1.374	0.092	15.1	4.0	6.5

TSO in-plane ultrasonic measurements. The in-plane moduli were calculated by dividing the TSI values by the density of the respective sample in table below.

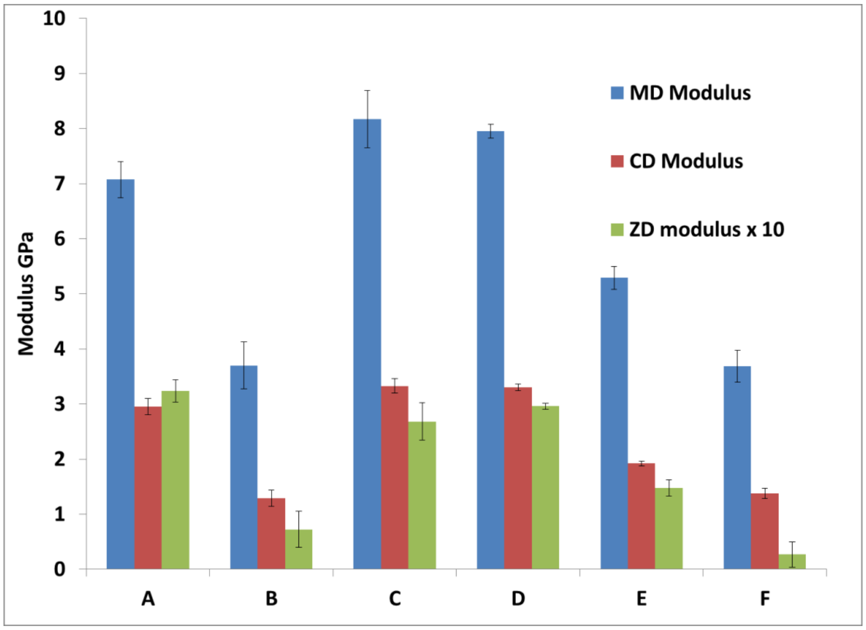
SAMPLE ID	TSI_MD		TSI_CD		TSI MS mod	TSI CD mod
A	8.63	0.06	3.82	0.04	11.84	5.24
B	4.69	0.07	1.94	0.33	7.59	3.14
C	9.19	0.24	3.96	0.22	11.78	5.07
D	8.92	0.15	3.84	0.16	11.07	4.76
E	6.36	0.39	2.34	0.2	8.85	3.26
F	5.22	0.46	2.21	0.2	8.58	3.63

Analysis of regression of MIT folds versus ultrasonic (OPUS) moduli in the 3 principal directions: MD, CD and ZD demonstrated in the small table.

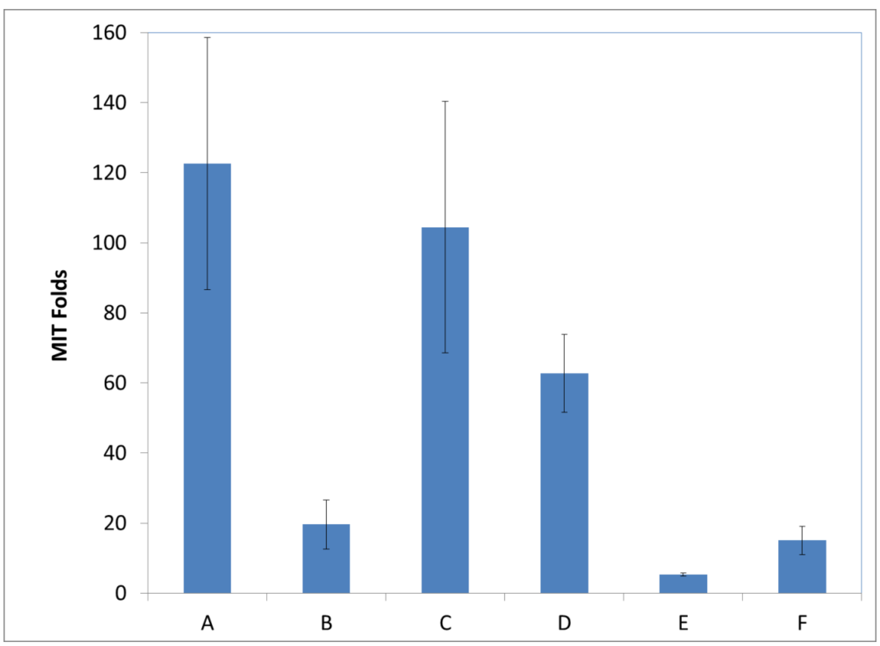
	RSQ's
MIT vs MD	0.633413
MIT vs CD	0.678392
MiT vs ZD	0.731346



Comparison of the in-plane OPUS determined elastic moduli and the corresponding values obtained by calculation and the TSO instrument output. The good correlation instills confidence in the different methods shown in graph.



The Summary of the in-plane (MD and CD) and out of plane (ZD) elastic moduli. Higher values indicate a better quality of sheet. Note the ZD modulus in the figure has its values multiplied by 10 to fit on the same scale.



MIT folds, the behavior appears to qualitatively follow the elastic moduli. A low elastic modulus given the same fiber characteristics would indicate a lower degree of bonding which would also be reflected in a fold endurance test, as shown in graph.

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January 21 ,2011.

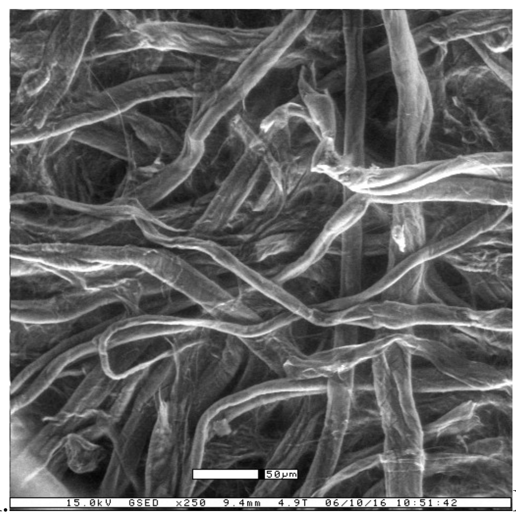
Experiment 6.

Hypothesis: Paper treated with passivation polymers has fungistatic properties.

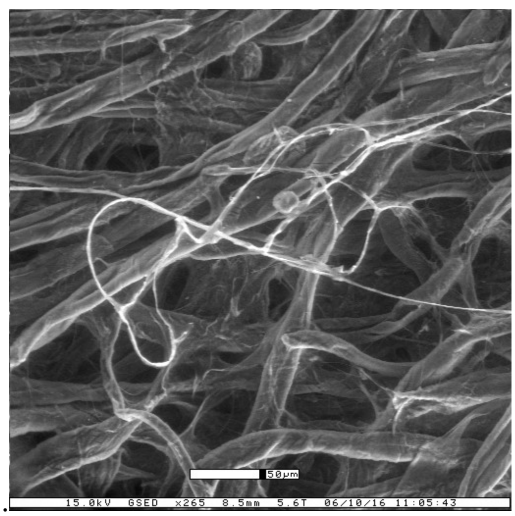
Materials:

Treated printer paper disks
Control printer paper disks
Agar plates with
Previously moldy paper

Procedure: Into starch agar plate a paper disk of treated and untreated paper is placed. On the other two sides a piece of already moldy paper from two different growths was placed, to ensure mold growth. It is anticipated that they will grow an unknown mold that exists on cellulose on the agar plates and the untreated paper, but that the treated paper will resist the mold.

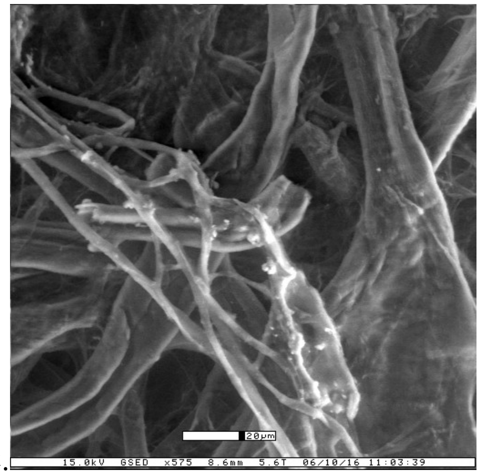


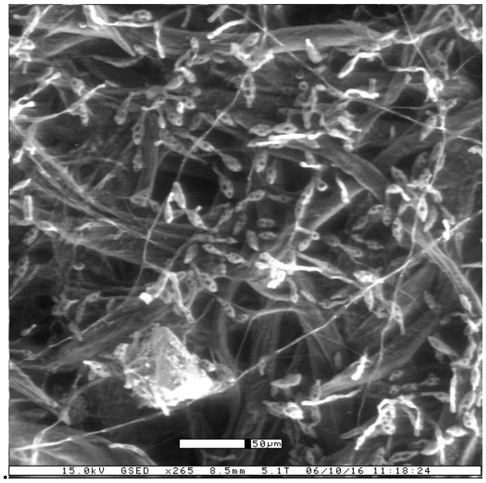
A.



B.

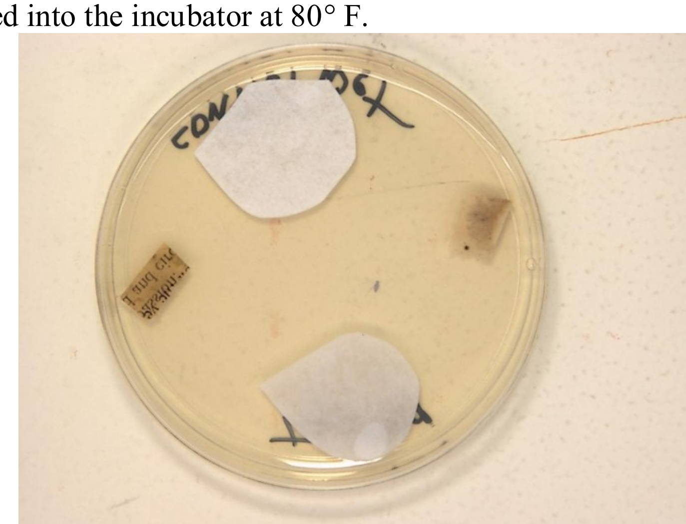
These ESEM images show: A. Whatman filter paper control and B. Whatman filter paper with mold.

C. 

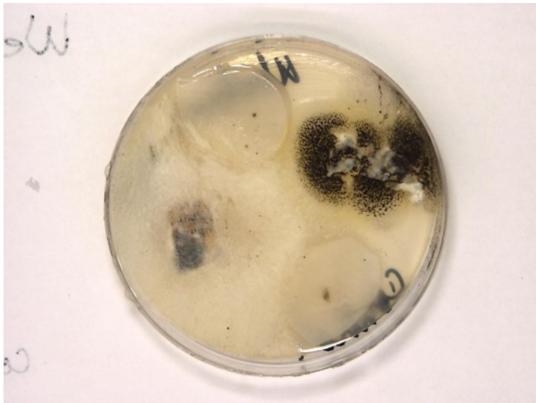
D. 

These ESEM photos show: C. Whatman paper with mold magnified and D. Whatman paper with mold.

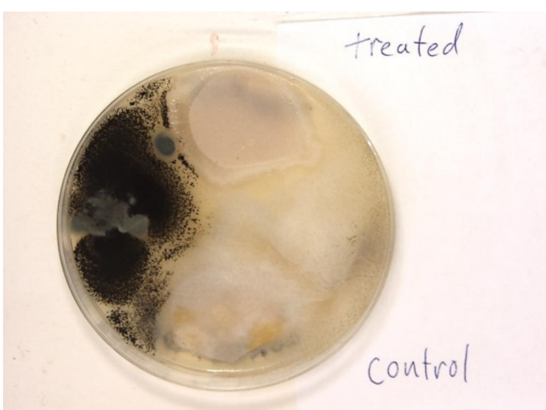
Data: All of the plates looked like this before they went into the incubator. Printer paper was selected to maintain a standard of production. The plates were labeled on the bottom and placed into the incubator at 80° F.



After three days, they were photographed. The “wet” side is the treated paper and the control is on the opposite side. There is mold growing out from the infected paper, but it is not growing on the treated paper. There seems to be some activity on the control paper, but more time is necessary for additional growth.



After four days (seven days total) of incubation, there is mold growing on the control paper. The treated paper has resisted mold growth, exhibiting fungistatic properties.



The third plate is also exhibiting fungistatic properties. It looks like the black mold has begun to grow on the periphery, but this is just the mycelium from the plate growing around it, rather than on it. The control is growing its own colonies

Conclusion: After seven days of incubation with paper eating mold present, the treated paper exhibits fungistatic properties.

Experiment 7.

Hypothesis: Using passivation polymers in conjunction with calcium carbonate will deacidify and place a buffering agent within the paper. This will also add strength to the paper.

Materials:
Pages from *Off on a Comet* 1957
Pages from *Concordance* 1812
Printer paper
Whatman paper
Calcium carbonate powder
Deionized water
95% MTMS + 5% Si oil

Procedure:
1. Set a control aside of all paper.

2. Wash selected paper using calcium carbonate aqueous bath. Repeat as necessary. Measure acid content.

3. Treat paper with Passivation Polymer spray after applying $CaCO_3$ powder by brushing surface with powder on both sides. Allow 1 day for drying and curing. Measure acid content.

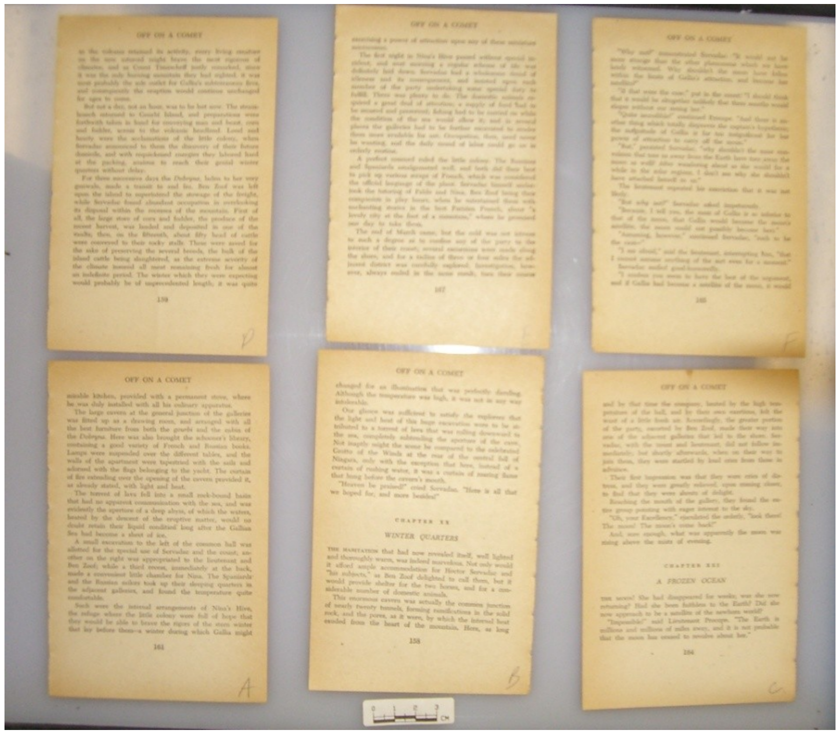
4. Place $CaCO_3$ and Passivation Polymer into spray bottle. Spray acidic paper. Allow 1 day for drying and curing. Measure acid content.

5. Place paper washed like the treatment 2. into 95% MTMS + 5% Si oil solution. Allow 1 day for drying and curing. Measure acid content.

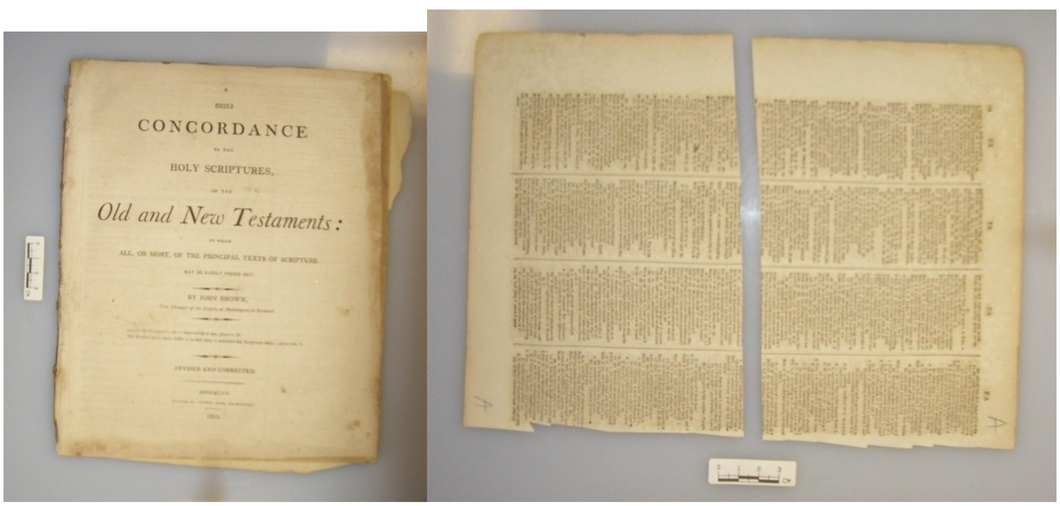
6. Place paper into 95% MTMS + 5% Si oil solution. Allow 1 day for drying and curing. Measure acid content.

TAPPI T509 cold water extraction:

Place macerated dry paper sample into a beaker
Add 70ml of deionized H_2O.
Leave for an hour using a magnetic stirrer to agitate
Measure Ph at room temperature.

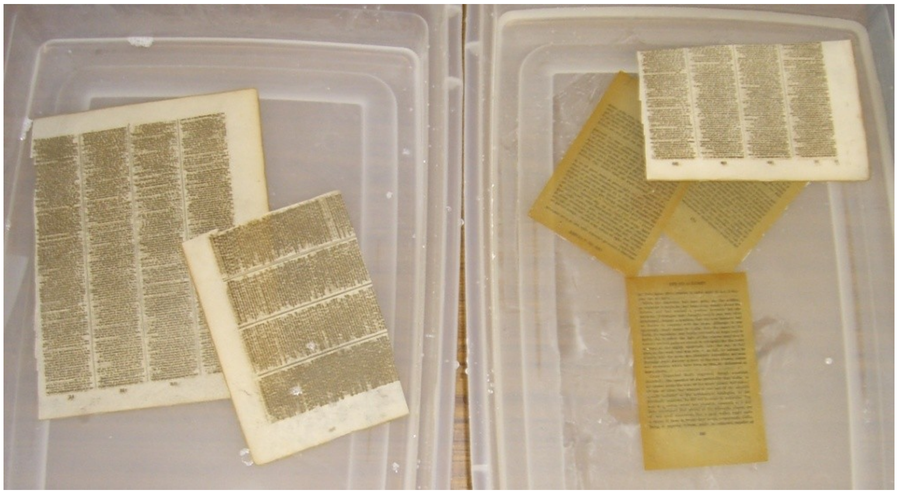


Discolored and weak paper from Off on a Comet labeled A-F.



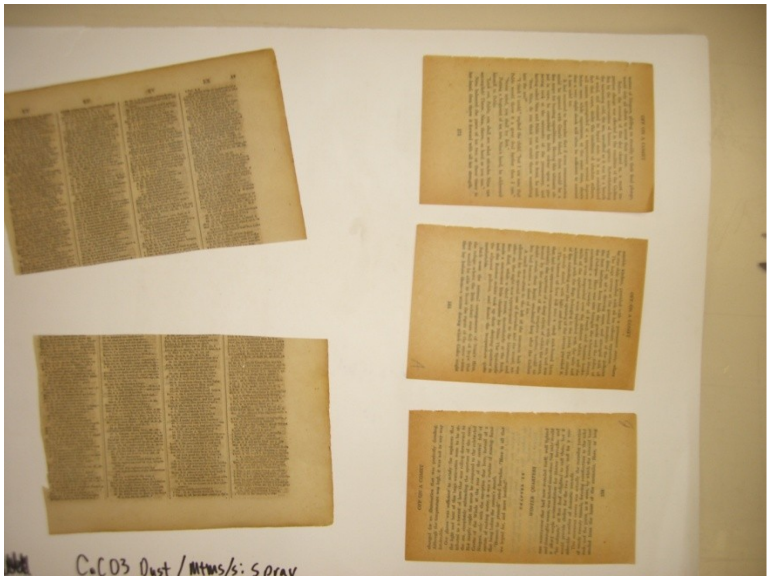
Paper from Concordance printed in New York in 1812.

Treatment 2: CaCO3 was added to the DI water. Each of the papers were washed six times. Each paper remained in each bath for 20 minutes. The initial bath was yellow, and in each successive bath less yellow was apparent. By the sixth bath, the water did not seem to have any color change. Each paper was removed and placed between a series of blotters and pressed with weights. The final blotter was left overnight to ensure complete drying.


Papers being washed in the final bath.

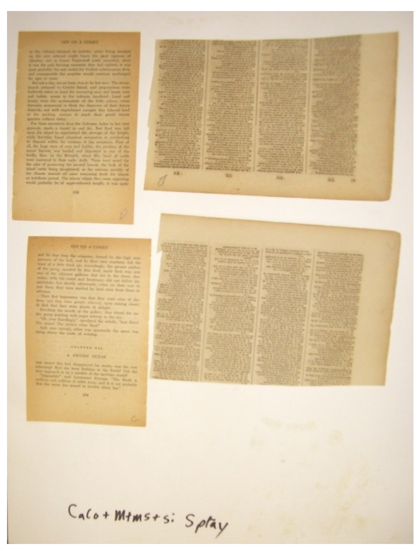
Treatment 3. CaCO3 was brushed on both sides. It was then sprayed with 95% MTMS + 5% Si oil solution.


Shows the application of CaCO3. After a small amount was placed onto the paper, it was brushed in with an small boar bristle paint brush. There did not appear to be any powder visible after treatment, but the paper did feel a little grainy.



Paper after brushing on the CaCO3 powder and then spraying with the solution.

Treatment 4. A solution of 95% MTMS + 5% Si oil with CaCO3 in suspension was prepared. It was sprayed onto the paper. The spray bottle with the CaCO3 in suspension had about a quarter of an inch of CaCO3 in the bottom of the bottle. This was shaken prior to its spray application onto each paper. The paper did not feel as grainy as the brushed on CaCO3 paper did, but if one ran their hand across the entire length of the paper, one might feel a little grainy, but if the paper was brushed with a light brush, it removed the excess CaCO3. This was conducted on all of the experimental paper.



Paper after the application of the sprayed CaCO3 and solution.

4. Some of the papers washed as in treatment 1. were placed into 95
oil solution.

5. Papers placed into 95% MTMS + 5% Si oil solution without any CaCO3.

Data: Cold water extractions were conducted on each sample and then averaged together. Two different pH Litmus papers were used: Baker Litmus paper and EMD Litmus paper.

Paper	Baker Litmus	EMD Litmus
CaCO3 solution in DI water no paper or treatment	pH 8	pH 7.5
Off on a Comet untreated control	pH 4.5 limit of paper	pH 3
Off on a Comet washed with DI water and CaCO3	pH 6.75	pH 6.5
Off on a Comet washed with DI water and CaCO3 and dipped into MTMS solution	pH 6.5	pH 6.5
Off on a Comet Dusted with CaCO3 and later sprayed with MTMS solution	pH 6.5	pH 6.5
Off on a Comet Sprayed with CaCo3 + Solution	pH 7.3	pH 6.9
Off on a Comet in 95% MTMS + 5% Si oil solution	pH 4.5	pH 4

Concordance untreated control	pH 4.5 limit of paper	pH 4
Concordance washed with DI water and CaCO3	pH 7	pH 6.5
Concordance washed with DI water and CaCO3 and dipped into solution	pH 7	pH 6.5
Concordance Dusted with CaCO3 and later sprayed with solution	pH 7	pH 7
Concordance Sprayed with CaCo3 + Solution	pH 7.5	pH 6.5
Concordance with 95% MTMS + 5% Si oil solution	pH 4.5 limit of paper	pH 4

Whatman # 1 control	pH 6.5	pH 6.5
Whatman #1 dusted with CaCO3 and sprayed	pH 7.5	pH 6.5
Whatman #1 Sprayed with solution and CaCO3	pH 7.5	pH 6.5
Printer paper control	pH 8	pH 8
Printer paper sprayed with Sprayed with CaCo3 + Solution	pH 8	pH 8

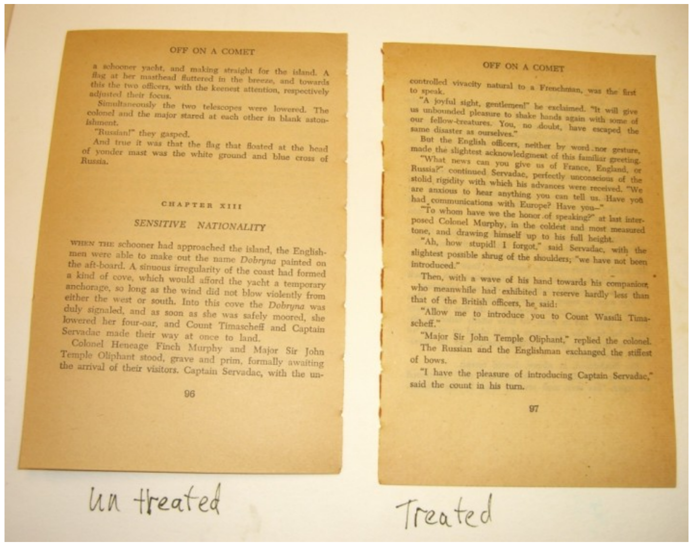
Results: CaCO3 provides an alkali that tests to a pH 8, so the highest possible pH of the papers would not exceed 8. As stated in the literature, a pH above 8 can have problems from too much alkaline buffer. The experimental book papers proved to be very acidic.

The washed paper performed as expected, and then adding the MTMS solution made no difference in pH, as is demonstrated by the pH of the untreated vs the MTMS treated controls. Both the conventional washing and the MTMS in conjunction with CaCO3 show a change in pH to a more stable state.

The Whatman paper was improved by the process as well. It was expected that the Whatman paper would be found to be neutral. Even though this was not the case, the paper improved after treatment.

Printer paper was found to have a pH 8. This was unchanged when treated with the spray.

The MTMS solutions rendered both of the book papers slightly (almost imperceptibly) darker and slightly (almost imperceptibly) translucent. It did not seem to discolor the Whatman paper. All of the paper retained the same texture and feel.



The dusted and the sprayed alkaline methods returned very similar results. The Off on a Comet results were better with the sprayed alkaline. This one step method is much easier to apply, versus the more time consuming, labor intensive two-step method of the dusted alkaline, is not necessary.

As a result of the deacidification studies, an unique discovery was made. As stated before, each beaker used to hold the paper to be measured contained one gram of paper cut into small squares in 70 ml of water that was agitated for one hour using a magnetic stirrer. Two beakers were left over night containing printer paper and water and 95% MTMS + 5% Si oil treated printer paper in water. The untreated printer paper turned into a slurry of indefinable, loose paper squares. The edges of each paper square looked ragged and loose. The treated printer paper looked the same as when it went into the water, the edges still crisp as it was originally cut. The untreated printer paper was replicated in 5 beakers and allowed to sit another night. All had the same appearance of a loose slurry with undefined edges on each paper square . After 48 hours, the treated paper was the same, while the first batch of printer paper was even more dissolved.

The beakers, from left to right are: 48 hour old untreated printer paper, 24 hour old untreated printer paper, and 48 hour old treated paper.

The beakers, from left to right are: 48 hour old untreated printer paper, 24 hour old untreated printer paper, and 48 hour old treated paper.

This demonstrates that the untreated printer paper suffered from both the relaxing of the fiber matrix and a breaking of the bonds due to the presence of water and agitation. While the treated paper maintained its original ordered alignment.

Conclusion: The results of the controls demonstrated the presence of acid within the paper. CaCO3 provides an alkali that tests to a pH 8. When the paper is washed in a conventional treatment protocol, it does remove or stabilize the acids present, but washing is labor and time intensive, and renders the paper weak. Treating the washed paper with MTMS solution did not change the pH, and it made it stronger. The best treatment, as determined by these experiments, is the CaCO3 in a 95% MTMS + 5% Si oil solution. It raised the pH, it did not affect the feel or texture, it generally did not affect its appearance, and it deposited an alkali buffer into the paper.

The unintended discovery of the maintenance of the shape of the individual pieces of paper of the treated printer paper in water shows that the paper is made stronger and retains more of its original characteristics as a result of treatment. This demonstrates that the solution strengthens the paper even when wet, as the fibers in the treated printer paper did not relax enough to become completely loosened in water. The fibers in the untreated printer paper relaxed significantly. The addition of water over time caused the breaking of both the fiber to fiber bonds and some of the bonds within the cellulose fibrils. The paper additives in the untreated paper became dislodged from the original paper matrix during this time as well. The paper additives remained in place in the treated paper, due to either the fibers not relaxing enough to cause the additives to become loose, or that the solution caused the additives to become more strongly bonded to the matrix of the paper.

APPENDIX B

Artifact 2000.001.6-3

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/8/05 **Artifact No.** 2000.001.6-3 **Initials** ebe

Description and Condition:
poster
3.5 ft x1.5 ft
yellow cross

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Results: ☐ Excellent ☐ Good ☒ Fair ☐ Poor

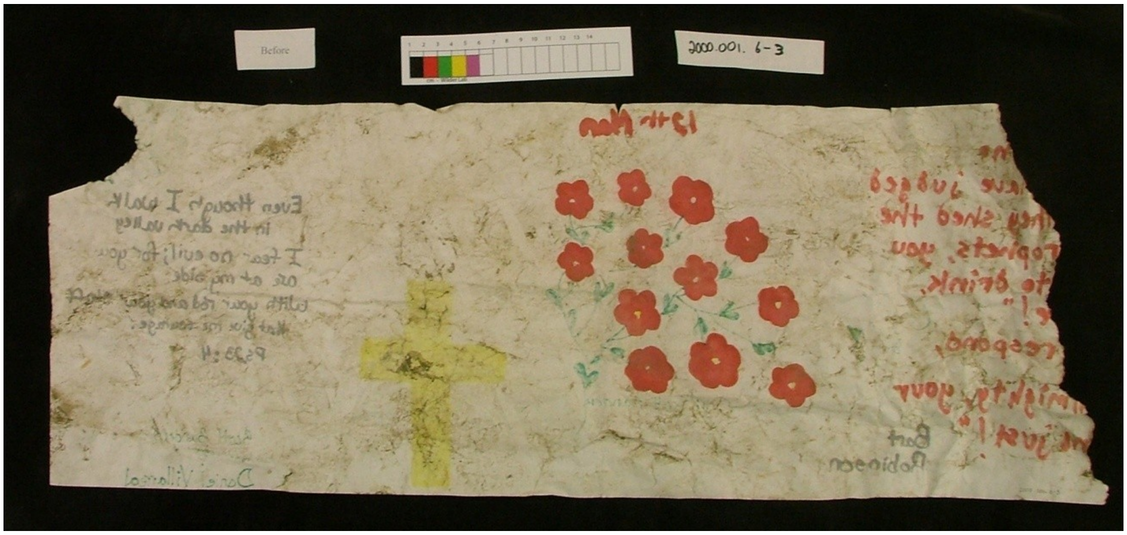
Testing:
ink
lights

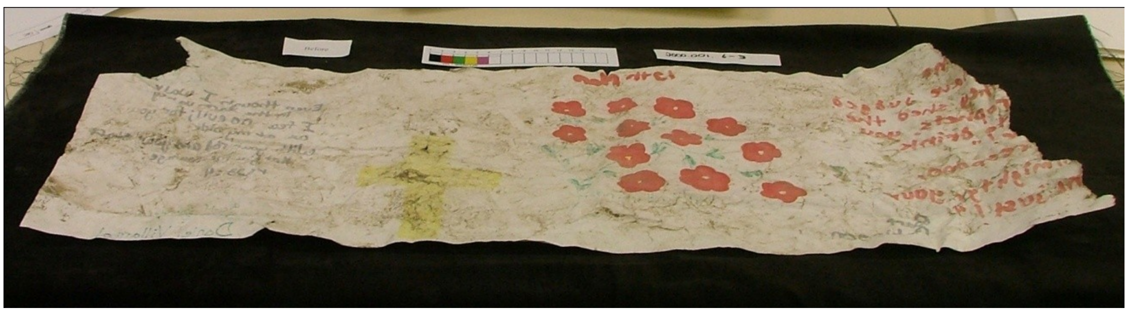
Conclusions:
It looked much better after cleaning. As soon as it went into MTMS/Si the red started to bleed and instead of yanking it out , I thought that it might be possible to get rid of the excess by continuing to wash it. This just made the entire part of the poster in treatment turn from white to light pink

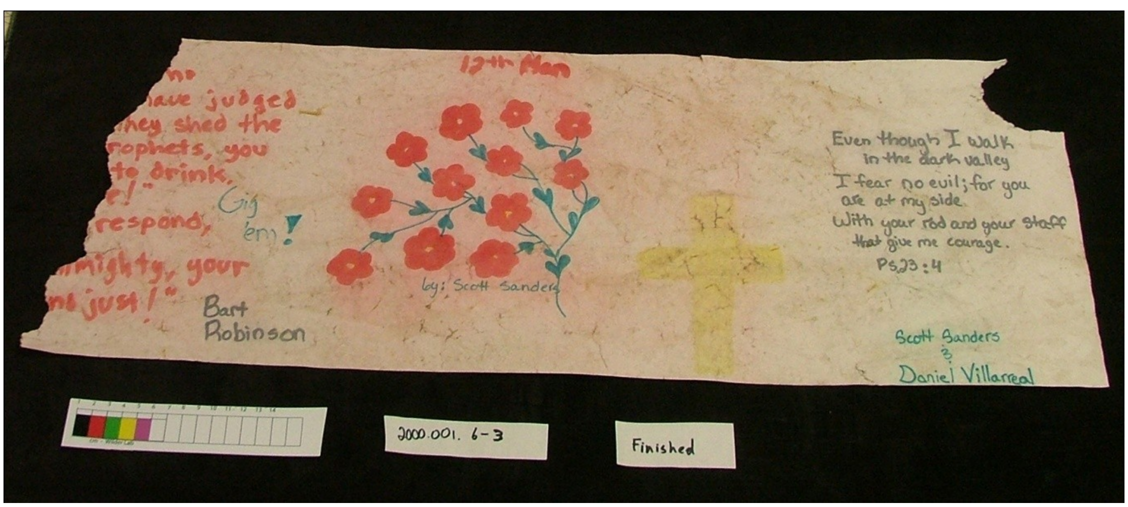
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments: MTMS caused bleed, possibly due to unknown alcohol present in MTMS


Before
2000.001. 6-3




12th Man
have judged
hey shed the
rophets, you
to drink.
e!"
respond,
mighty, your
ns just!"
Gig 'em!
Bart Robinson
by: Scott Sander
Even though I walk in the dark valley
I fear no evil; for you are at my side.
With your rod and your staff that give me courage.
Ps.23:4
Scott Sanders & Daniel Villarreal
2000.001. 6-3
Finished


2000.001. 6-3
Finished

Artifact 200.001.4583

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/7/05 **Artifact No.** 2000.001.4583 **Initials** ebe

Description and Condition:
Framed newspaper clippings
smaller image taped to bigger image
frame with cardbord and non-archival backing
very yellowed, but in good condition

Proposed Treatment:
Wash
flatten
tape removal
MTMS/Si

Testing:
light ink

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

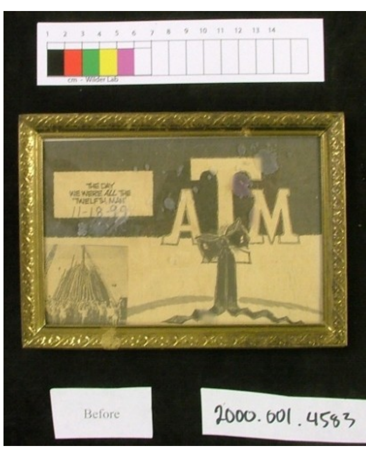
Conclusions:
While it was hoped that the newsprint would lighten up, it only did a little. It was decided that the tape removal would be too invacive if the adhesive was removed, as the newsprint is very thin and brittle and that the MTMS may render it safe. If it does yellow or start the degrade the paper further, steps should be taken to remove the tape

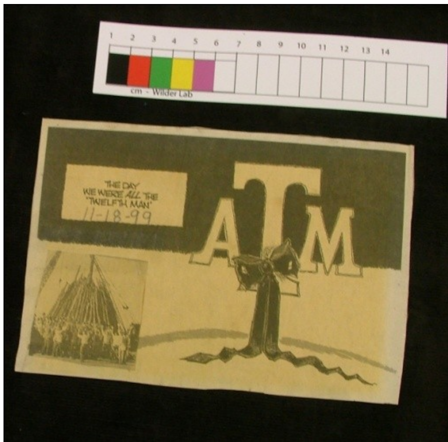
There seems to be a mystery stain that developed after treatment.

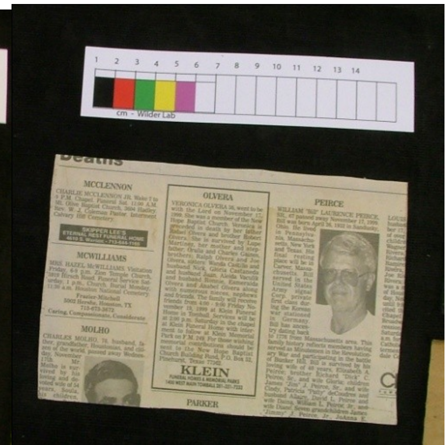
Graphic Record

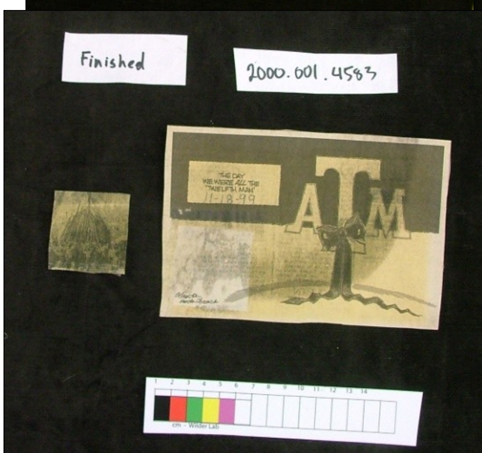
	Before	During	After
Color photo	x		x

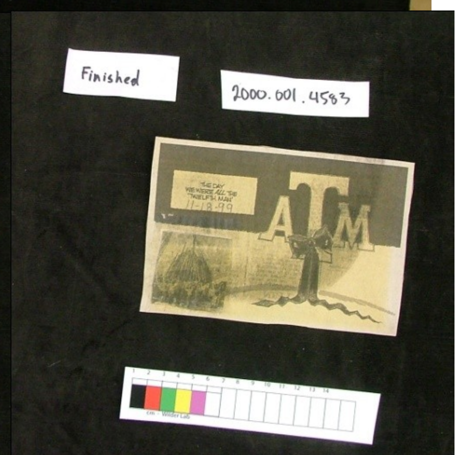
Additional Comments:




THE DAY
WE WERE ALL THE
"TWELFTH MAN"
11-18-99
ATM


MCCLENNON
OLVERA
PEIRCE
MCWILLIAMS
MOLBO
KLEIN
PARKER


Finished
2000.001.4583


Finished
2000.001.4583


Finished
2000.001.4583


Finished
2000.001.4583

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-28 **Initials** ebe

Description and Condition:
construction paper folded lengthwise-yellow?
some surface dirt
mold
Front: Green ink with faint hearts in ink, blue heart sticker

Back: Orange ink run, red/pink pigment

Inside: "God bless the Aggies Sarah K"
smiley face in pencil
"Kindergarten, st matthews, san antonion
2 stickers-hearts

Proposed Treatment:
Wash in ethanol
flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

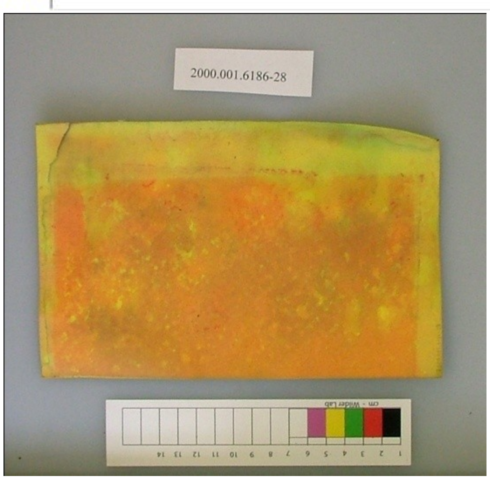
Testing:
Lights
Ink-water soluble, but alright in ethanol

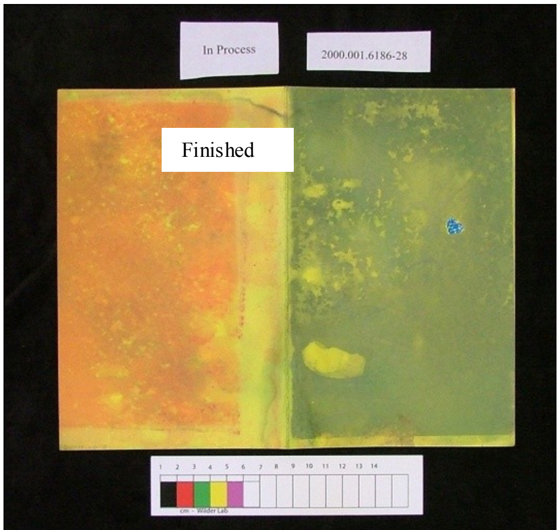
Conclusions:
looks better with cleaning
stronger and more flexible

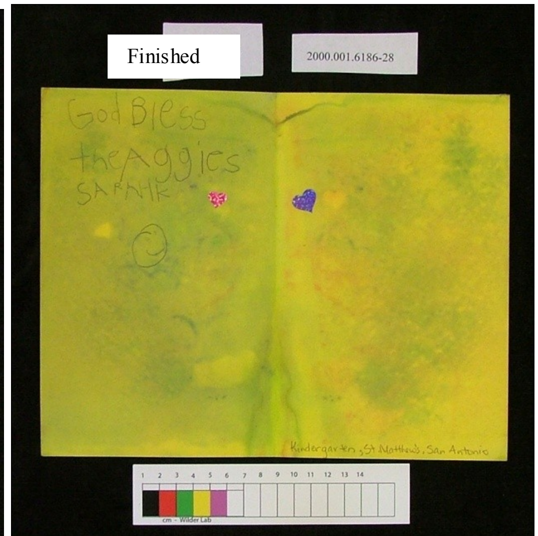
Graphic Record

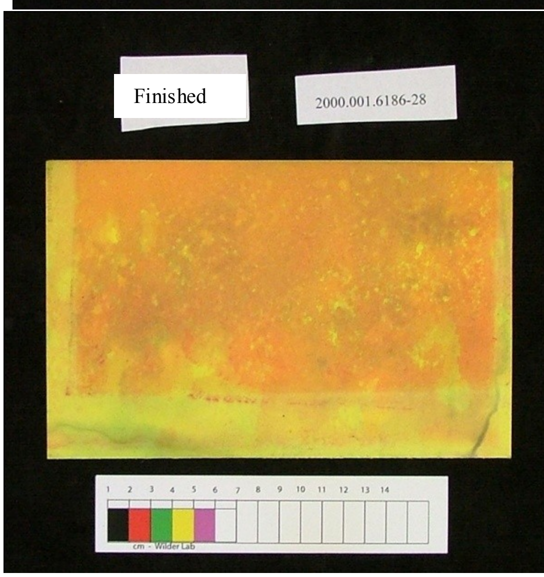
	Before	During	After
Color photo	x		x

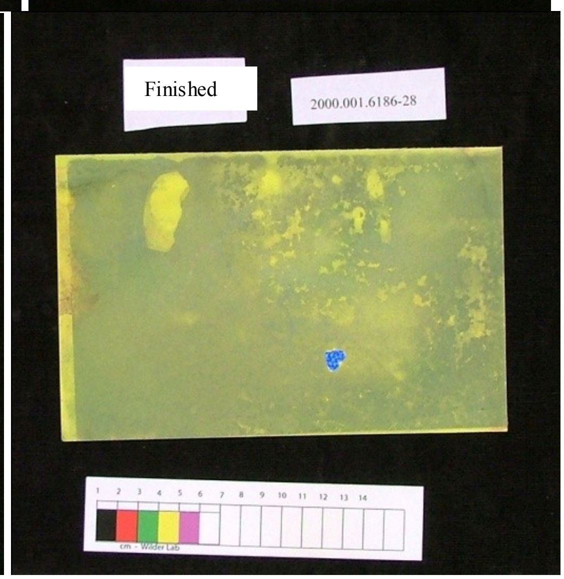
Additional Comments:




In Process
2000.001.6186-28
Finished


Finished
2000.001.6186-28
God Bless
the Aggies


Finished
2000.001.6186-28


Finished
2000.001.6186-28

Artifact 2000.001.6186-30

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-30 **Initials** ebe

Description and Condition:
folded construction paper-yellow?
Surface dirt and mold

Front: 'Jessica" + 2 heart stickers and green pigment
Back: green and yellow on back
Inside: "God Bless the Aggies"-pencil
"kindergarten San Antonio"-ink

Proposed Treatment:
Humidify
MTMS/SI
flatten

Results: ☐ Excellent ☒ Good ☒ Fair ☐ Poor

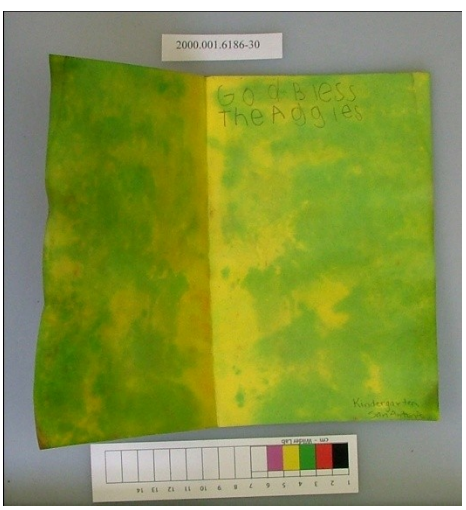
Testing:
Light
ink-h2osoluble

Conclusions:
Finshed-clean
mold dead
still maintains some warping
Thougth it was possible to flatten After MTMS

Graphic Record

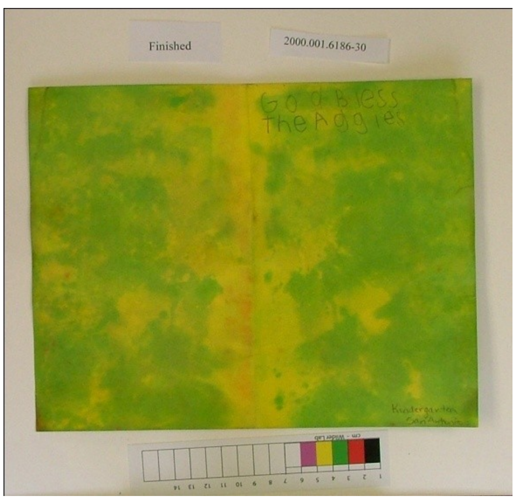
	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.6186-30


Finished
2000.001.6186-30


Finished
2000.001.6186-30
God Bless
The Aggies


Finished
2000.001.6186-30
JESSICA

Artifact 2000.001.6186-31

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-31 **Initials** ebe

Description and Condition:
construction paper folded lengthwise-purple
mold/surface dirt
Front: ink runs , grass, God Bless the Aggies
Back: "San Antonio..." in Pencil
rose stickers
green and orange inks

Proposed Treatment:
Wash
Flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

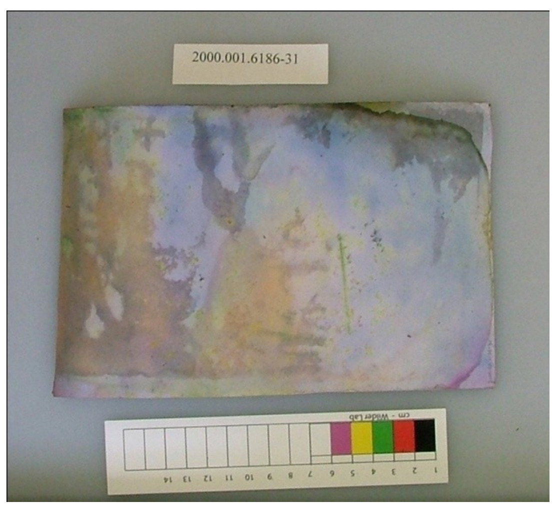
Testing:
Light
water soluble ink
ethanol used for cleaning

Conclusions:
Mold is dead
it looks better and is more flexible

Graphic Record

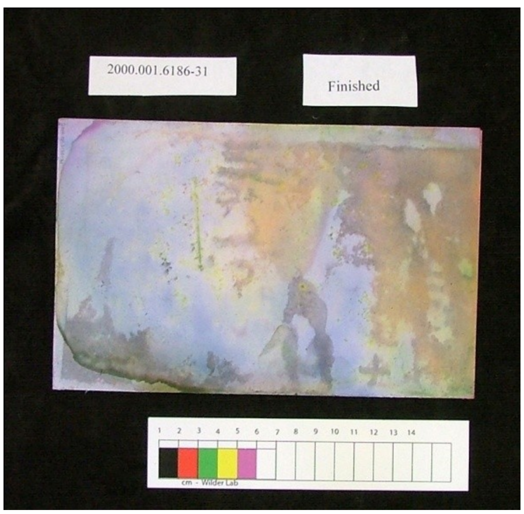
	Before	During	After
Color photo	x	x	x

Additional Comments:




2000.001.6186-31
cm - Wilder Lab


2000.001.6186-31
Finished
cm - Wilder Lab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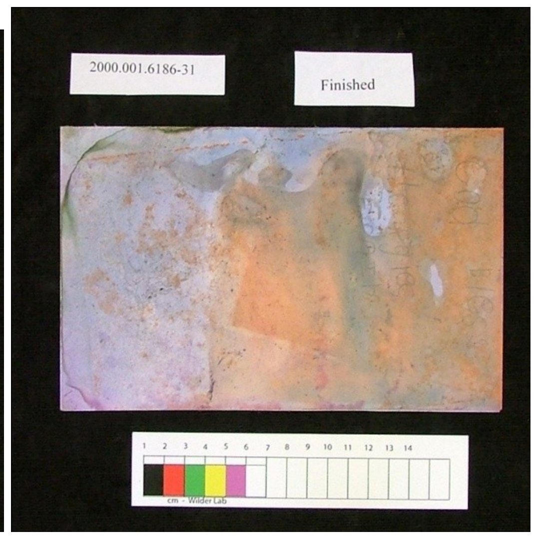
Finished
cm - Wilder Lab


2000.001.6186-31
Finished
cm - Wilder Lab

Artifact 2000.001.6186-32

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-32 **Initials** ebe

Description and Condition:
Construction paper folded lengthwise-yellow?
surface dirt and mold

Front: "God Bless the Aggies michaelS' in pencil
back: orange ink run
inside: "kindergarten st. matthews school San Antonio" in ink
2 butterfly stickers 1 rose sticker
blue curvy line

Proposed Treatment:
Humidify
Mtms/si
flatten
mechanically clean

Results: ☐ Excellent ☐ Good ☒ Fair ☐ Poor

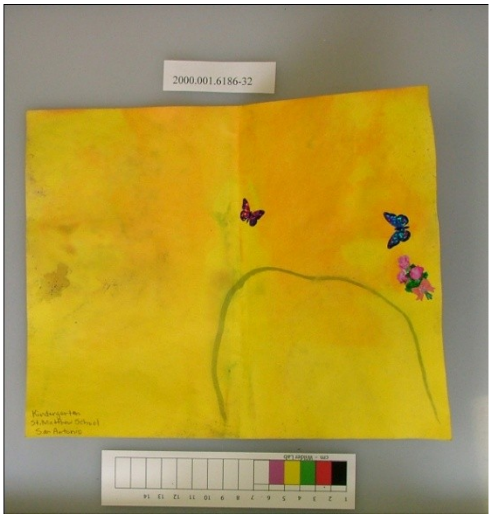
Testing:
Light-nothing
Ink-h2o soluble

Conclusions:
This was one of the first papers to go into treatment. As a result it is not flat due to the earlier belief that it could be flatten after MTMS treatment. The mold is dead and the document is stronger and not brittle

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments: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Finished
2000.001.6186-32


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2000.001.6186-32


Finished
2000.001.6186-32

Artifact 2000.001.6186-33

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-33 **Initials** ebe

Description and Condition:
white envelope-sealed
surface dirt
mold
Front: orange and blue ink run
Back: "To an Aggie" in pencil
Blue/orange/red ink run

Letter folded inside
8.5x11
"Sara 24 Stubbs
God Bless Aggies! We love you"

Proposed Treatment:
Open envelope
wash
flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

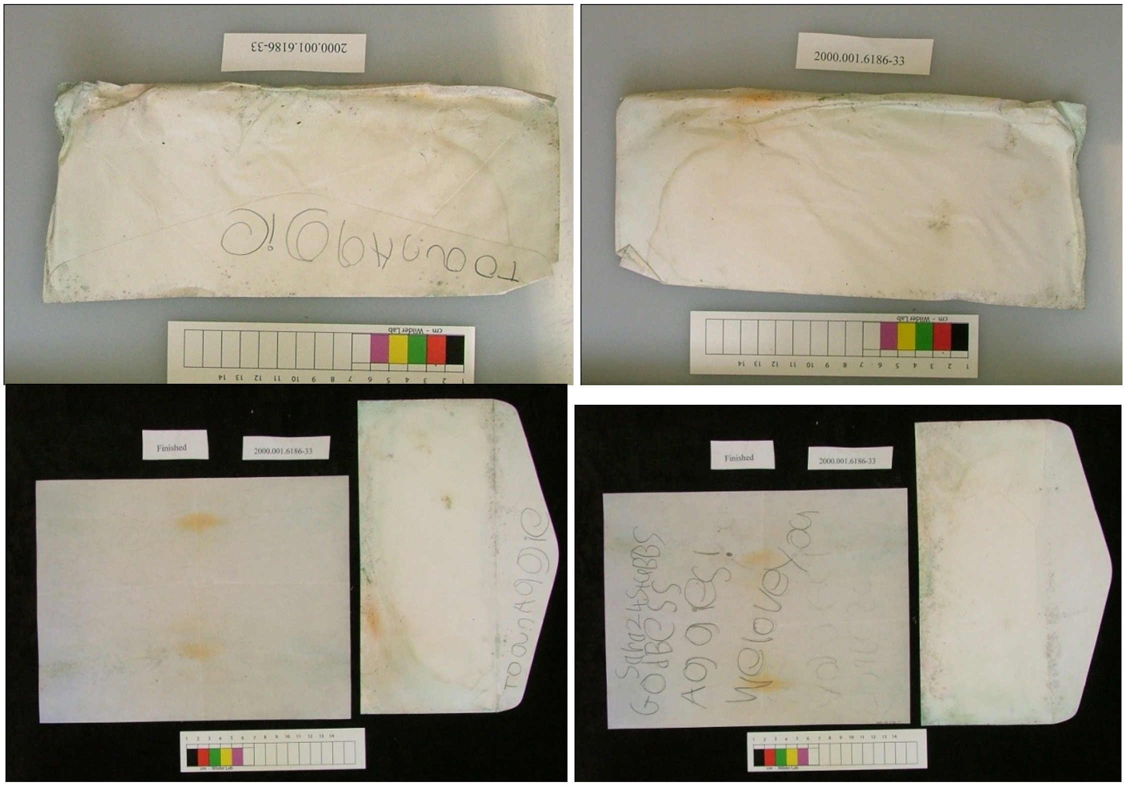
Testing:
lights-nothing
h2o soluble
ethanol safe

Conclusions:
Mold killed/surface dirt removed
Ethanol bath to open
treatment made it stronger

Graphic Record

Color photo Before During After

Additional Comments:


2000.001.6186-33
2000.001.6186-33
Finished
2000.001.6186-33
Finished
2000.001.6186-33

Artifact 2000.001.6186-34

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-34 **Initials** ebe

Description and Condition:
white envelope sealed
surface dirt and mold
Front and back -blue, black and green ink run. Yellow ink

Letter inside: 8.5x11 blank with ink run like envelop

Proposed Treatment:
open letter
wash
flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
Lights-UVA sensitive, but nothing distinctive
h2o soluble ink
ethanol safe

Conclusions:
Ethanol bath to open the letter
live mold and surface dirt removed

MTMS/SI made it stronger

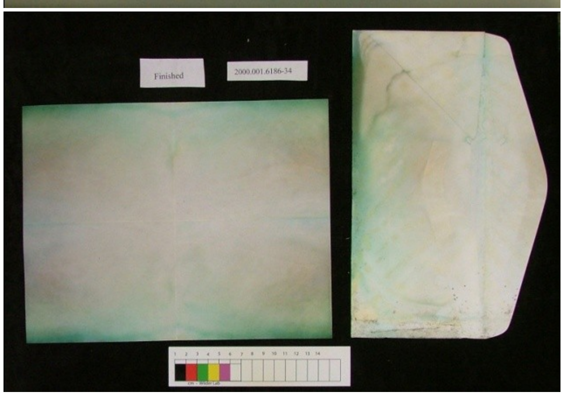
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6186-34


2000.001.6186-34


Finished
2000.001.6186-34


Finished
2000.001.6186-34

Artifact 2000.001.6186.-35

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

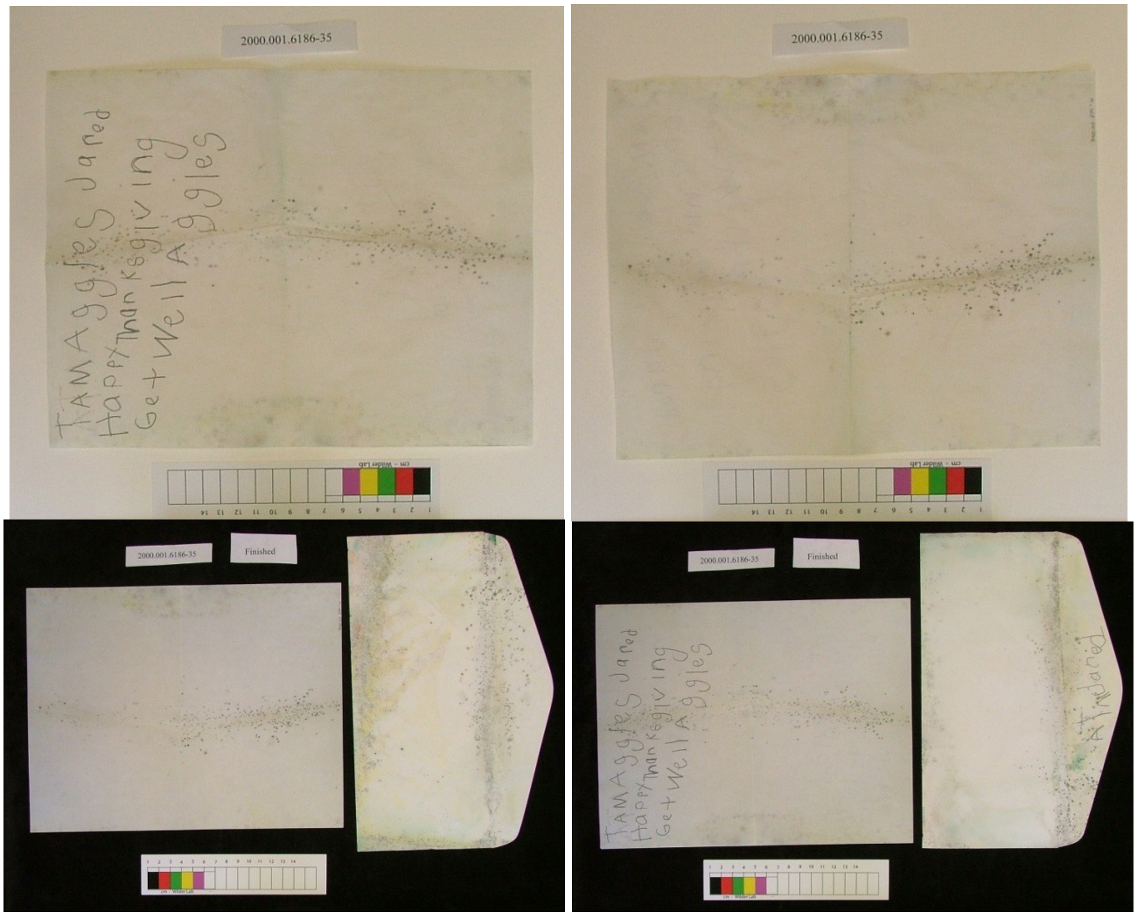
Date 10/7/05 **Artifact No.** 2000.001.6186-35 **Initials** ebe

Description and Condition:	white envelop sealed surface dirt and mold Front: Some green ink run Back: "ATM jared" in pencil green pigment letter: 8.5x11 "Tamaggies jared happy thanksgiving get well aggies"	**Proposed Treatment:**	Open letter wash in ethanol flatten MTMS/Si treatment
		Results:	☐ Excellent ☒ Good ☐ Fair ☐ Poor
Testing:	Lights-UVA ink is water soluble ethanol used	**Conclusions:**	opened letter in ethanol bath killed mold removed surface dirt improved flexibility

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6186-35
2000.001.6186-35
2000.001.6186-35
Finished
2000.001.6186-35
Finished

Artifact 2000.001.6186-36

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-36 **Initials** ebe

Description and Condition:
White envelope -sealed
Mold/ surface dirt
Front: "Alla" in pencil
green pigment
blue/yellow/purple ink
Back: green pigment

Letter folded inside 8.5x11"
Pencil drawing - architectural features
"Aggies"

Proposed Treatment:
Open letter
Wash in Ethanol
Flatten
MTMS/si treatment

Results: ☐ Excellent ☐ Good ☐ Fair ☐ Poor

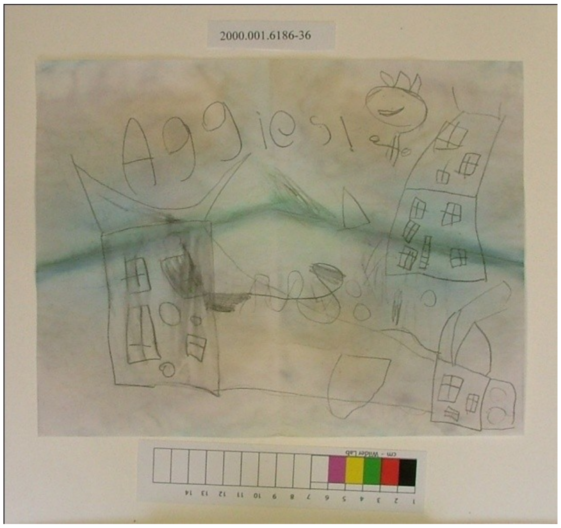
Testing:
Lights
Ink h2o soluble, not ethanol or acetone
adhesive tests

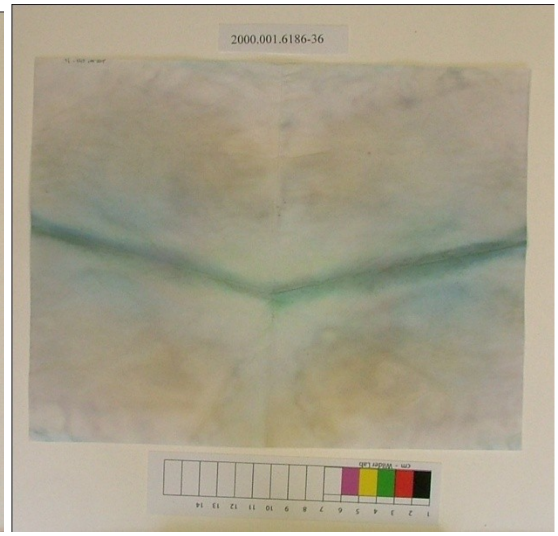
Conclusions:
Ethanol bath to open
remove mold/surface dirt

Graphic Record

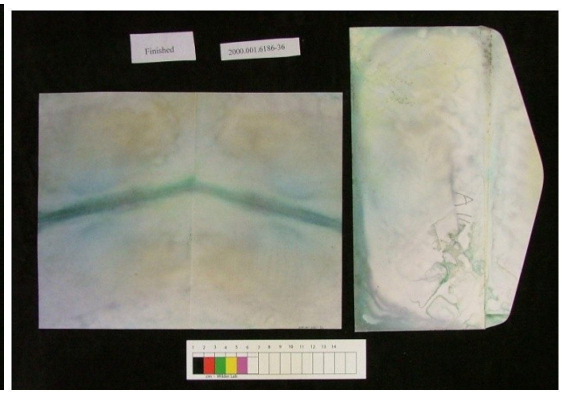
	Before	During	After
Color photo			

Additional Comments:


2000.001.6186-36


2000.001.6186-36


Finished
2000.001.6186-36


Finished
2000.001.6186-36

Artifact 2000.001.6186-37

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-37 **Initials** ebe

Description and Condition:
White envelop
mold
surface dirt
sealed
Ink on envelope may be from the letter inside
yellow ink is only where the letter is

Letter-blank ecept from ink rum

Pressed together with 38,36,35,34,33

Proposed Treatment:
Open enverlope
wash in ethanol
flatten letter
MTMS/si treatment

Results: ☐ Excellent ☒ Good ☒ Fair ☐ Poor

Testing:
Light-nothing distinctive

H2o soluble
ethanol safe

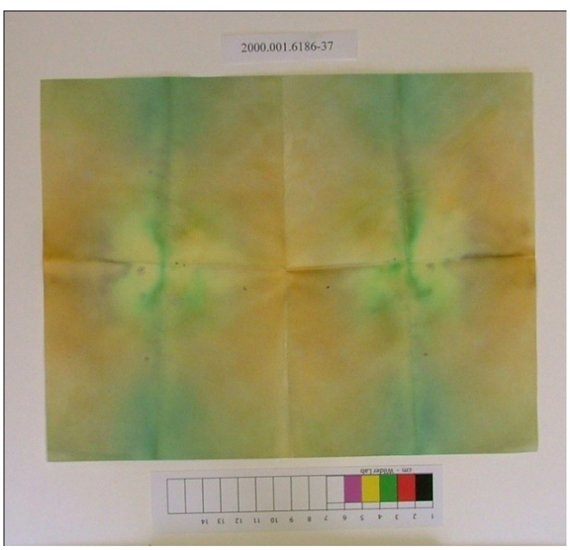
Conclusions:
ethanol bath killed mold and allowed cleaning

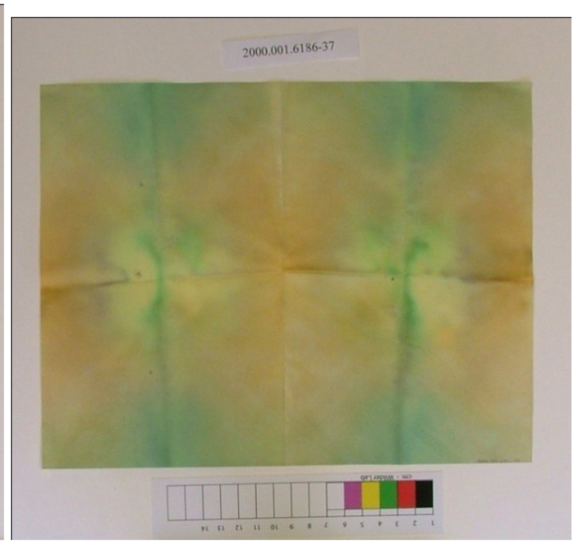
During humidification, the letter got wet, so there are water marks

Graphic Record

	Before	During	After
Color photo	x	x	x

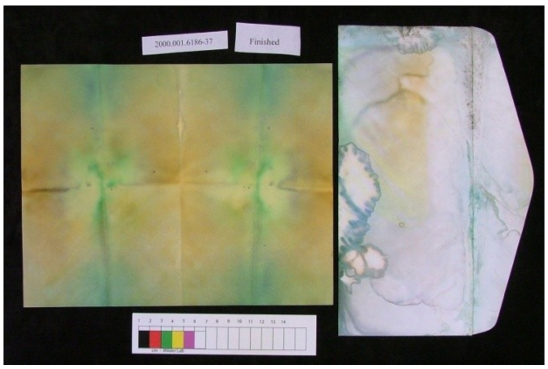
Additional Comments:






2000.001.6186-37


2000.001.6186-37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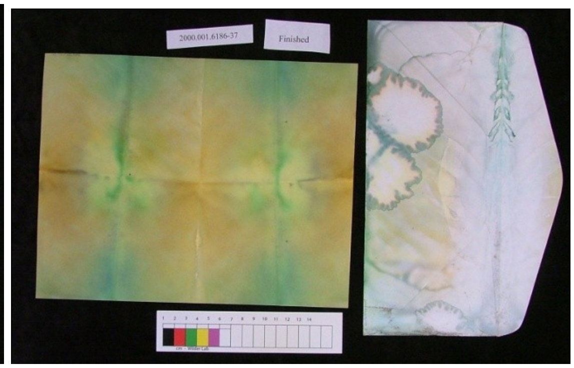
Finished


2000.001.6186-37
Finished

Artifact 2000.001.6186-38

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-38 **Initials** ebe

Description and Condition:
White envelope-sealed
surface dirt
mold
Front: hearts in crayon and pencil in four corners
"To an Aggie" in pencil
2 blue ink runs
green paint/pigment in corner
Back: Orange and blue ink run

Letter folded with creases inside
Front: "God bless Aggies..."
2 flowers, 4 black crayon forms
Back: sun, blue skies in pencil and crayon
Hand 'turkey' in pencil and crayon

surface dirt and mold

Proposed Treatment:
open envelope
wash
flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
Lights
Ink test with ethanol and h2o

Conclusions:
Opened by soaking it in ethanol soaked blotter

humidified to flatten

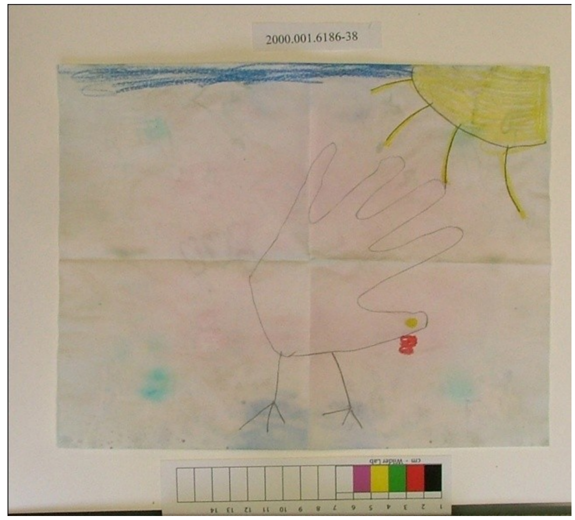
MTMS treatment killed the mold and strengthened it

Graphic Record

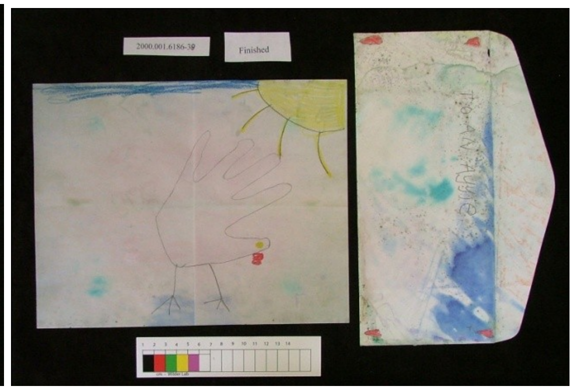
	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6186-38
God Bless
Ayyies!
We lo very ou.


2000.001.6186-38


Finished


Finished

Artifact 2000.001.6186-39

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-39 **Initials** ebe

Description and Condition:
White envelope-sealed
Surface dirt and Mold
Front of en.-lots of blue ink run
creasing/folding on the left side
Back-2 blue inks

Letter-tightly folded
11X17 inches
pencil drawing-possibly "Brats" girl

Proposed Treatment:
Open Letter
Humidify-due to possible ink run
Flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

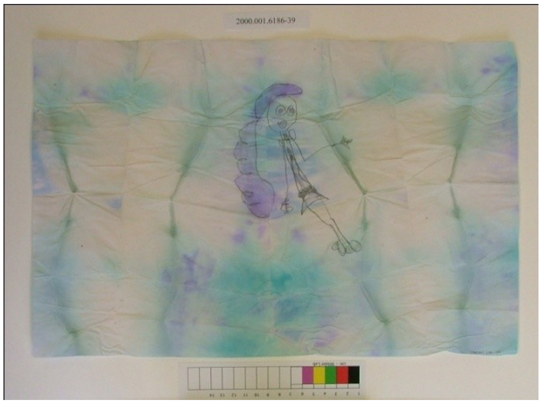
Testing:
Lights-no effect
Ink tests-h2o soluble
ethanol safe

Conclusions:
The envelope was opened using ethanol
After humidification, the letter was flattened
seems much stronger
Mold is dead and surface dirt removed

Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments: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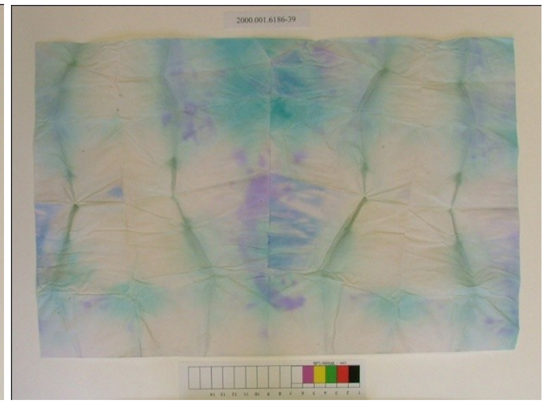
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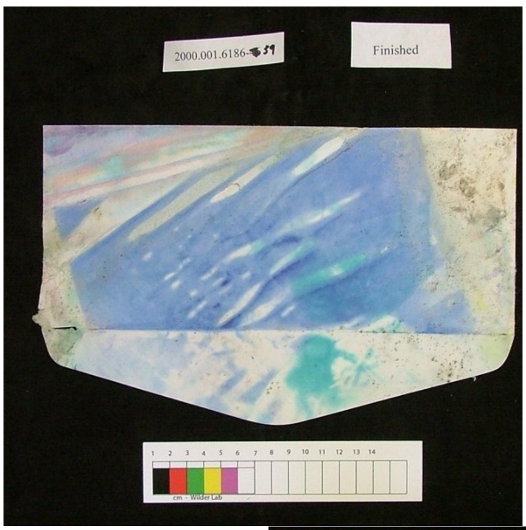
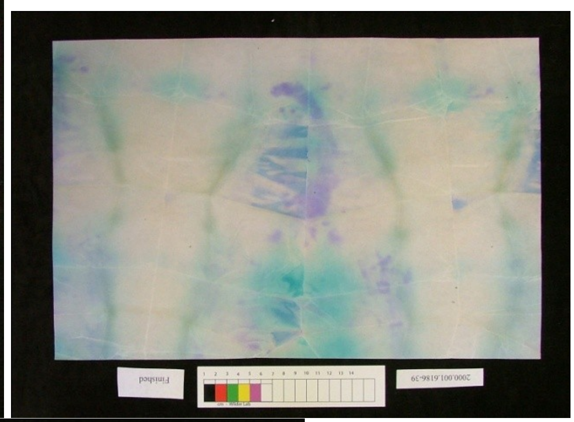
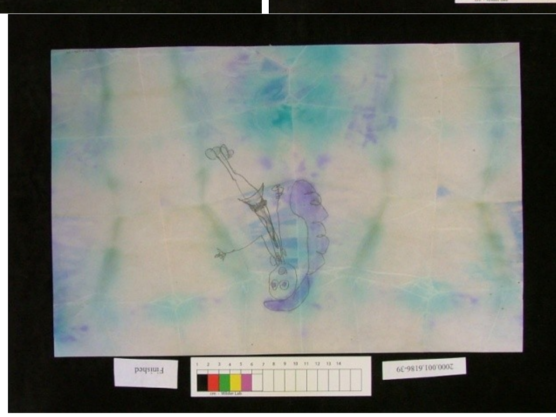

2000.001.6186-39
Finished
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm – Wilder Lab





Artifact 2000.001.6186-40

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date	10/7/05
Artifact No.	2000.001.6186-40
Initials	ebe
Description and Condition:	yellow envelop- adhesive missing mold/surface dirt Front: may have had some writing in green Back: "Aggies!" ? in green with ink run Letter: white paper letter covered in ink that had ran-red and blue mold 3 creases total
Proposed Treatment:	wash flatten MTMS/Si treatment
Results:	☐ Excellent ☒ Good ☐ Fair ☐ Poor
Testing:	ink lights ethanol safe h2o soluble
Conclusions:	looks better mold dead much stronger

Graphic Record

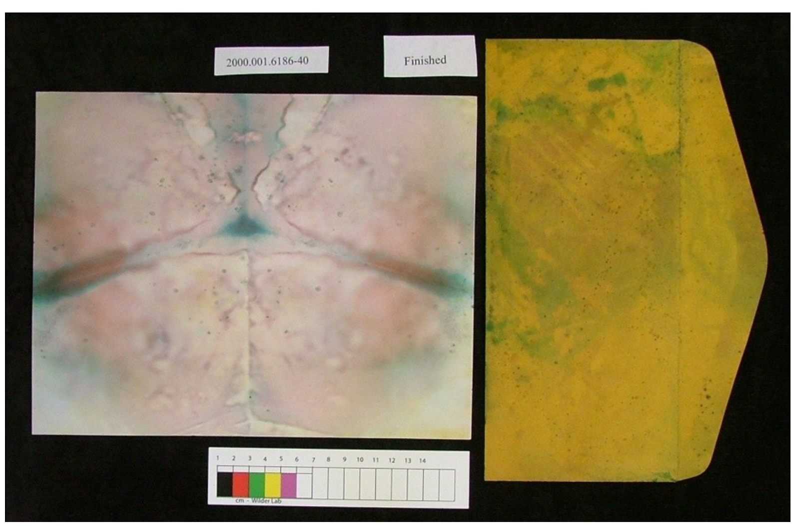
	Before	During	After
Color photo	x	x	x

Additional Comments:	


2000.001.6186-40
cm - Wilder Lab


2000.001.6186-40
cm - Wilder Lab


2000.001.6186-40
Finished
cm - Wilder Lab


2000.001.6186-40
Finished
cm - Wilder Lab

Artifact 2000.001.6186.-41

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-41 **Initials** ebe

Description and Condition:
sealed white envelope
lots of h2o soluble ink runs
"matthew m" in pencil on back
mold/surface dirt

letter inside with two folds

clearly pressed together with envelop 2000.001.6186-42

Proposed Treatment:
open envelop
wash in ethanol
flatten letter
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

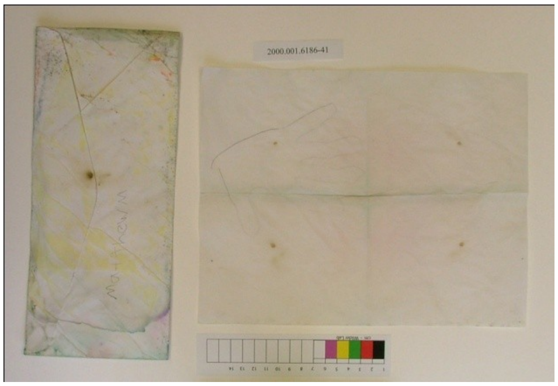
Testing:
Lights- nothing
ink tests
h2o soluble

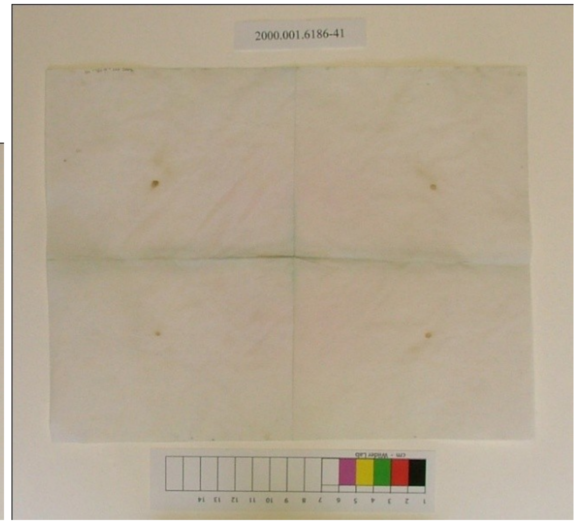
Conclusions:
it looks better and is stronger

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6186-41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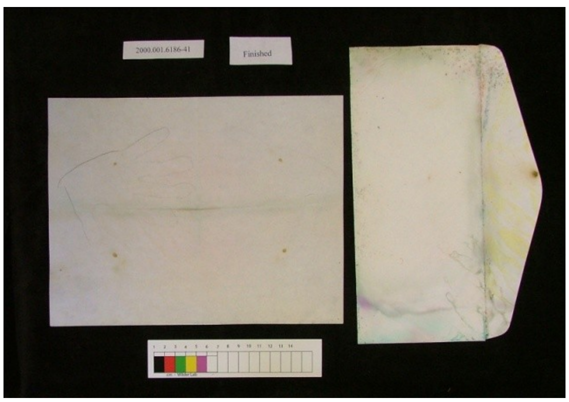
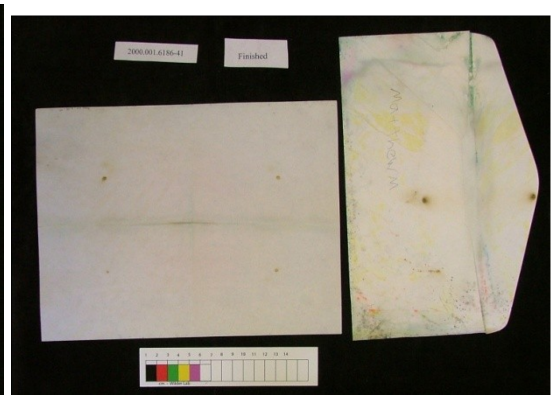

2000.001.6186-41
Finished


2000.001.6186-41
Finished

Artifact 2000.001.6186-42

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-42 **Initials** ebe

Description and Condition:
sealed white envelop
ink runs mold especially around edges
surface dirt
no writing

Letter inside with two folds
8.5x11 "bless' 'love' in faint ink
clearly pressed together with 41

Proposed Treatment:
open envelop
wash in ethanol
flatten envelope
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

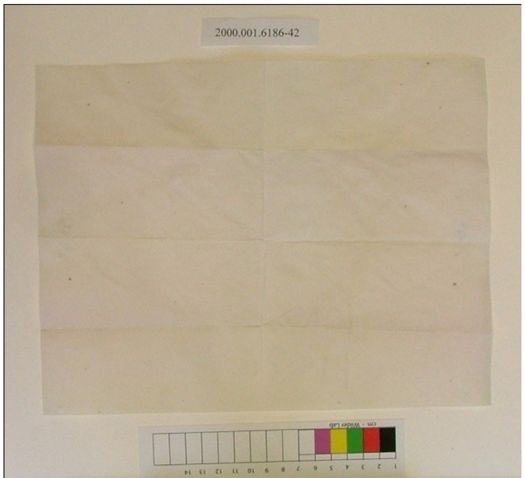
Testing:
light-UVA
ink test
test with ethanol-safe

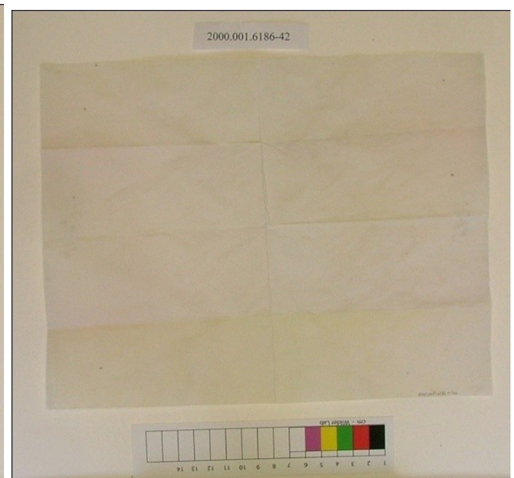
Conclusions:
opened envelope in ethanol bath.
Removed mold and surface dirt
Increased strength

Graphic Record

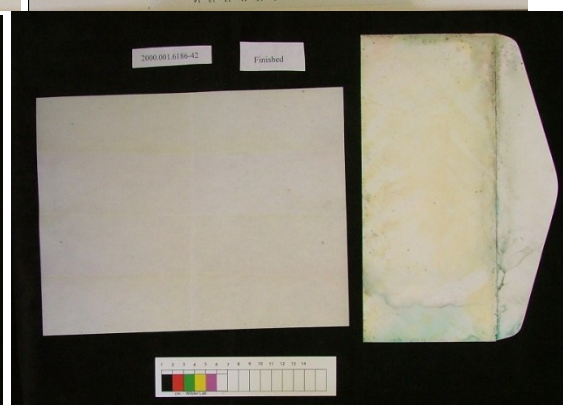
	Before	During	After
Color photo	x		x

Additional Comments:



2000.001.6186-42


2000.001.6186-42


2000.001.6186-42
Finished


2000.001.6186-42
Finished

Artifact 2000.001.6186-43

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-43 **Initials** ebe

Description and Condition:
envelope-yellow adhesive is gone
surface dirt
mold
ink runs
"Aggie" in pencil

White copy paper 8.5x11
blank
ink staining
mold
2 creases

Proposed Treatment:
remove surface
wash
flatten letter
maintain envelope bolds
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
lights
h2o soluble
ethanol safe

Conclusions:
looks much better and is much stronger

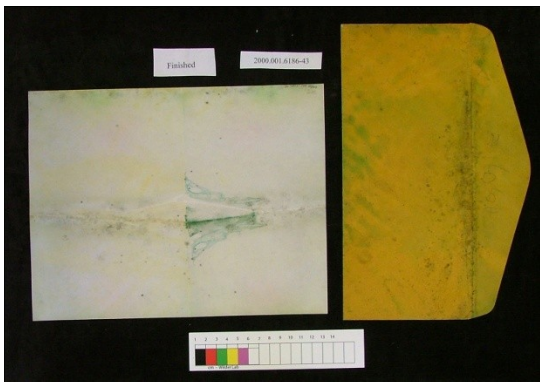
Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:


2000.001.6186-43


2000.001.6186-43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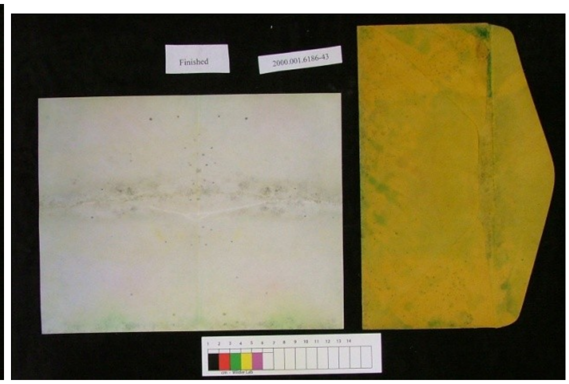
2000.001.6186-43


Finished
2000.001.6186-43

Artifact 2000.001.6186-44

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-44 **Initials** ebe

Description and Condition:
Water soluble in on cover
lots of surface dirt and mold
yellow envelop- no adhesive

Letter inside:
figure in pencil-possibly a "bratz"
probably colored with h2o based pens
2 folds

Proposed Treatment:
wash
flatten-humidify
maintain envelop shape
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

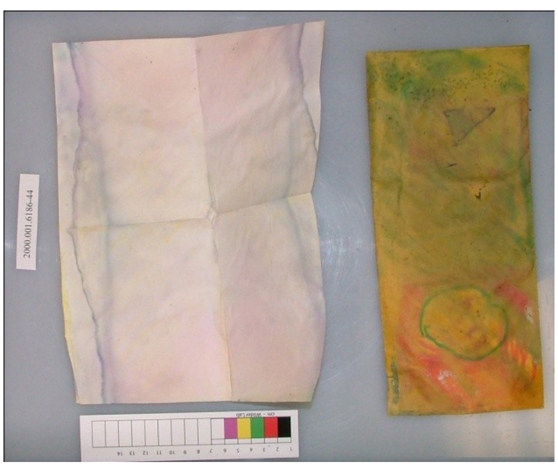
Testing:
lights showed nothing
h2o soluble

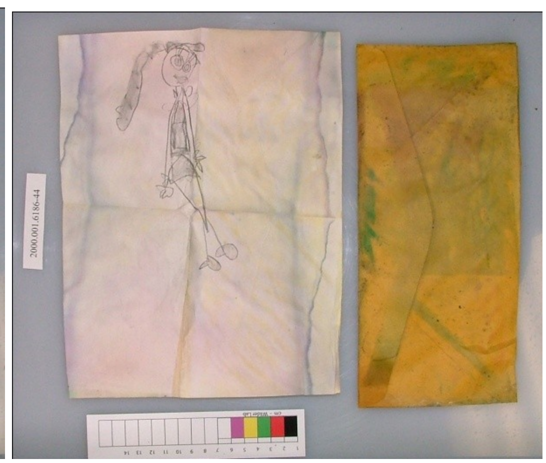
Conclusions:
looks better
much stronger

Graphic Record

	Before	During	After
Color photo			

Additional Comments:






2000.001.6186-44


2000.001.6186-44


2000.001.6186-44
Finished


2000.001.6186-44
Finished

Artifact 2000.001.6186-45

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6186-45 **Initials** ebe

Description and Condition:
Yellow envelop with mold stains
"to an aggie"
green ink run

Inside: White paper "god bless Aggies! we love you" in pencil
bleed of? red blue yellow ink
2 folds
Lots of mold
both in relatively good condition

Proposed Treatment:
wash to kill mold
flatten leter
maintain envelope shape
Mtma/si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

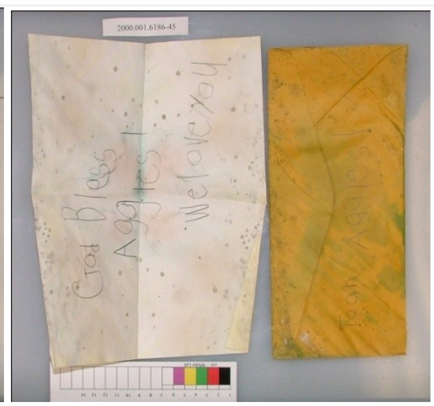
Testing:
Light test
pencil needs no testing
h2o soluble

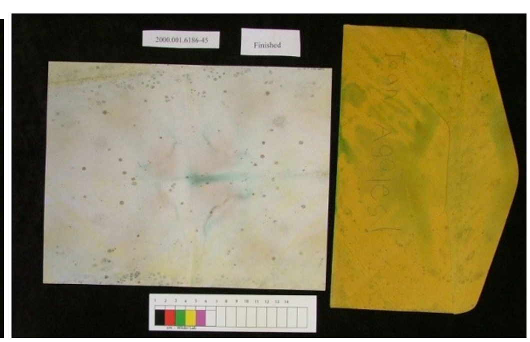
Conclusions:
looks good and stable with the mold having been killed

Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:





Artifact 2000.001.6187-1

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6187-1 **Initials** ebe

Description and Condition:
small paper card with a medal medalion inside a lamination.
surface dirt

Proposed Treatment:
wash and wipe clean

After consulting with the curator, it was decided that that would be the necessary treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

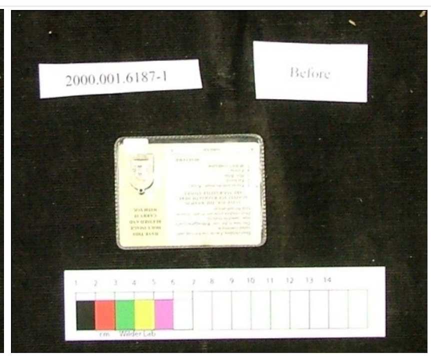
Testing:
lights showed nothing

Conclusions:
looks good, now that it was clean

Graphic Record

Color photo Before During After

Additional Comments:



Artifact 2000.001.6187-

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/01/05 **Artifact No.** 2000.001.6187-12 **Initials** ebe

Description and Condition:
card from flowers
ball point ink very faded, but could be read with enhansement
surface dirt and mold
It was stuch to and A&M Football program, so some of the ink transfered

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

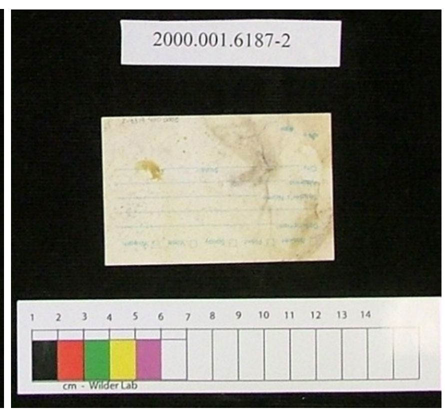
Conclusions:
looks better, as there is no way it could have been read before

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:

2



Artifact 2000.6187-4

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/20/05 **Artifact No.** 2000.001.6187-4 **Initials** ebe

Description and Condition:
bonfire card
glossy paper
ball-point pen ink
lots of surface dirt
mold

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

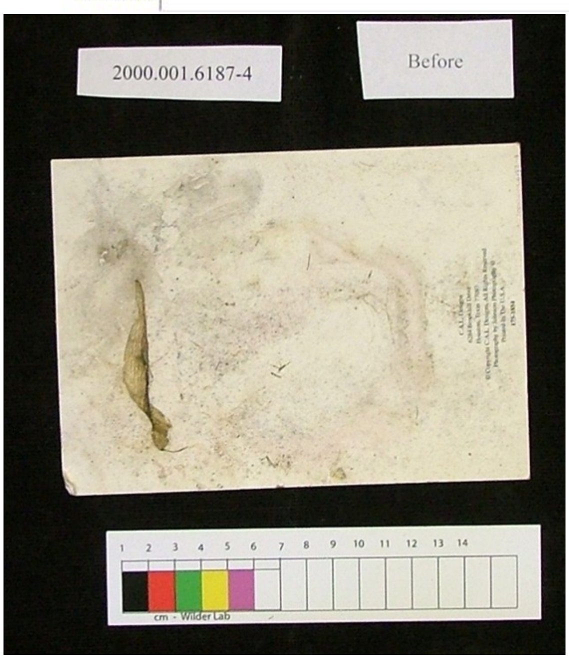
Testing:
ink
lights

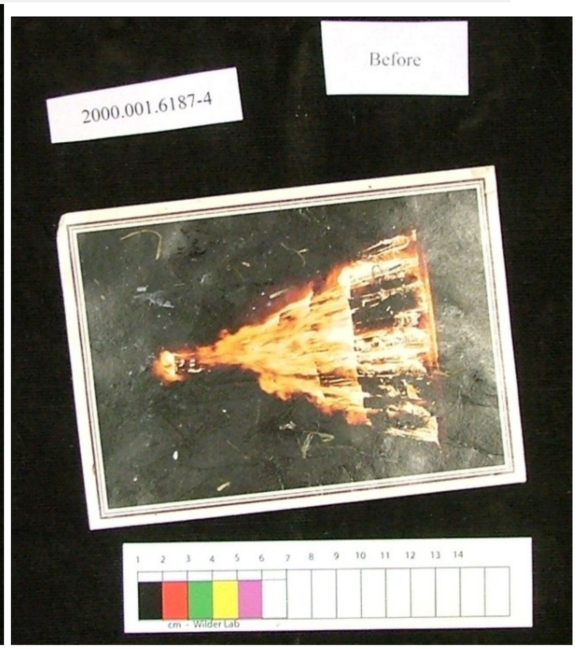
Conclusions:
looks alot better and stronger

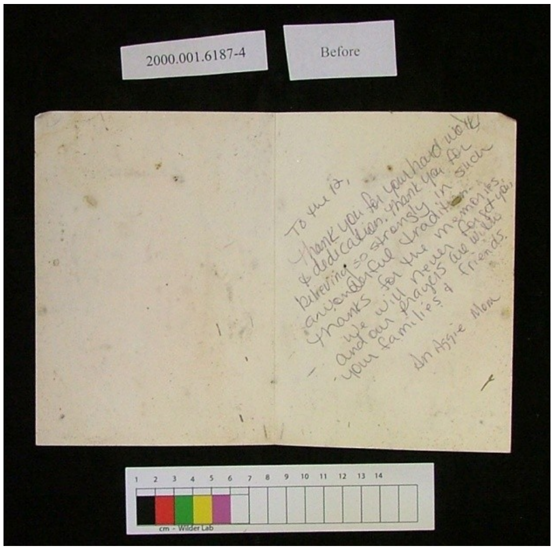
Graphic Record

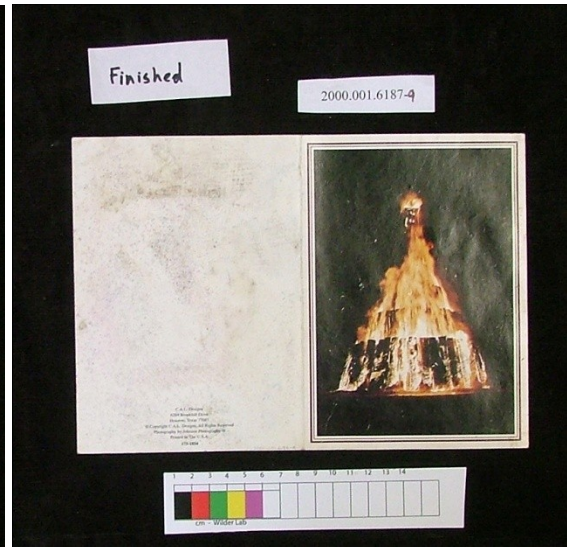
	Before	During	After
Color photo	x		x

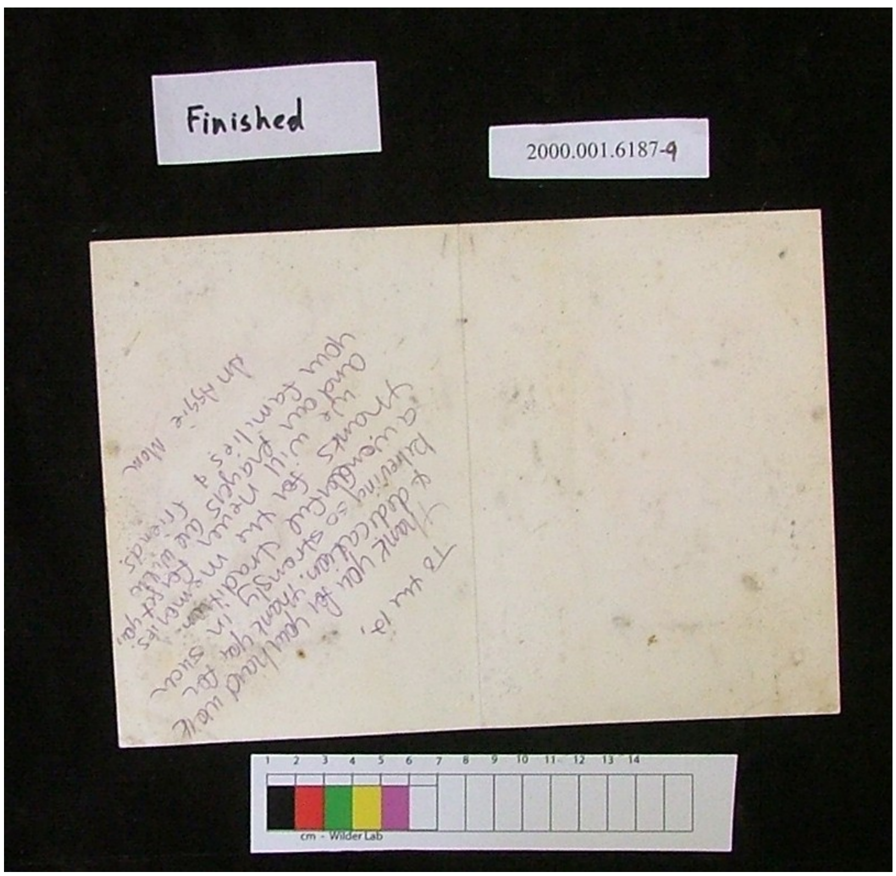
Additional Comments:






2000.001.6187-4
Before
To the 12,
Thank you for your hard work
& dedication. Thank you for
believing so strongly in such
a wonderful tradition.
Thanks for the memories.
We will never forget you
and our prayers are with you
your families & friends.
An Aggie Mom
cm - Wilder Lab


Finished
2000.001.6187-4
cm - Wilder Lab


Finished
2000.001.6187-4
cm - Wilder Lab

Artifact 2000.001.6187-5

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

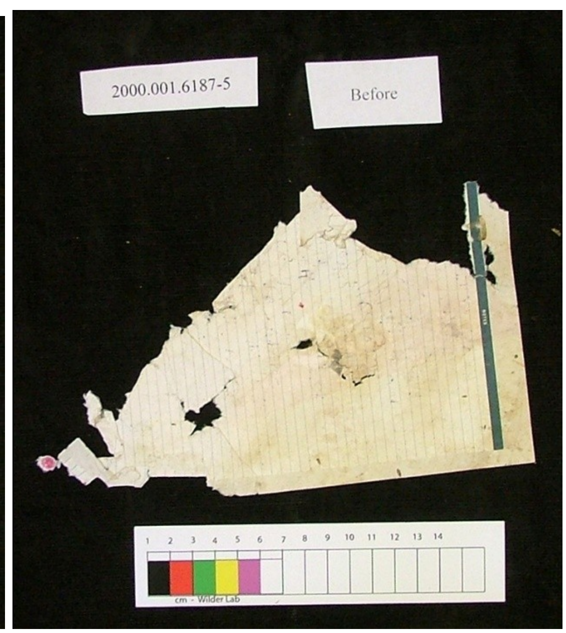
Date	11/5/05	**Artifact No.**	2000.001.6187-5	**Initials**	EBE

Description and Condition:	mangled piece of notebook paper several pieces ball point ink, but not readable very fragile
Proposed Treatment:	Humidify flatten attach to backing MTMS
Results:	☒ Excellent ☐ Good ☐ Fair ☐ Poor
Testing:	light-nothing ink is fine
Conclusions:	It looks alot better after backing and flattening much stronger after MTMS treatment

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:	




2000.001.6187-5
Finished


2000.001.6187-5
Finished

Artifact 2000.001.6187-6

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6187-6 **Initials** ebe

Description and Condition:
White 8.5x11 computer printout
"Find Rest..."
lots of surface dirt
mold
tears
folds
small missing areas
candle wax or oil

Proposed Treatment:
wash
flatten
mend
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

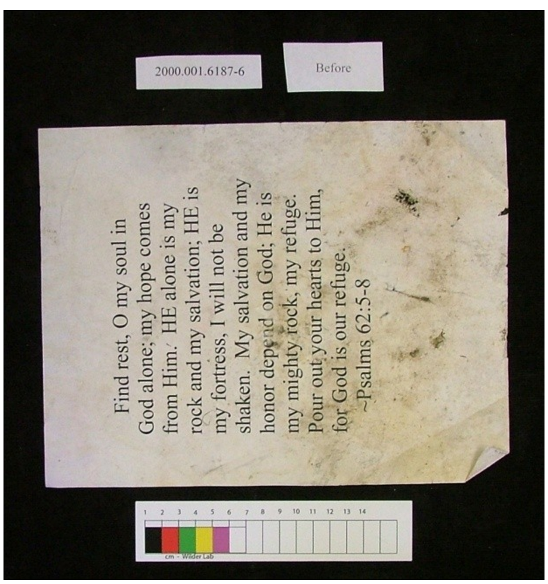
Testing:
lights ink

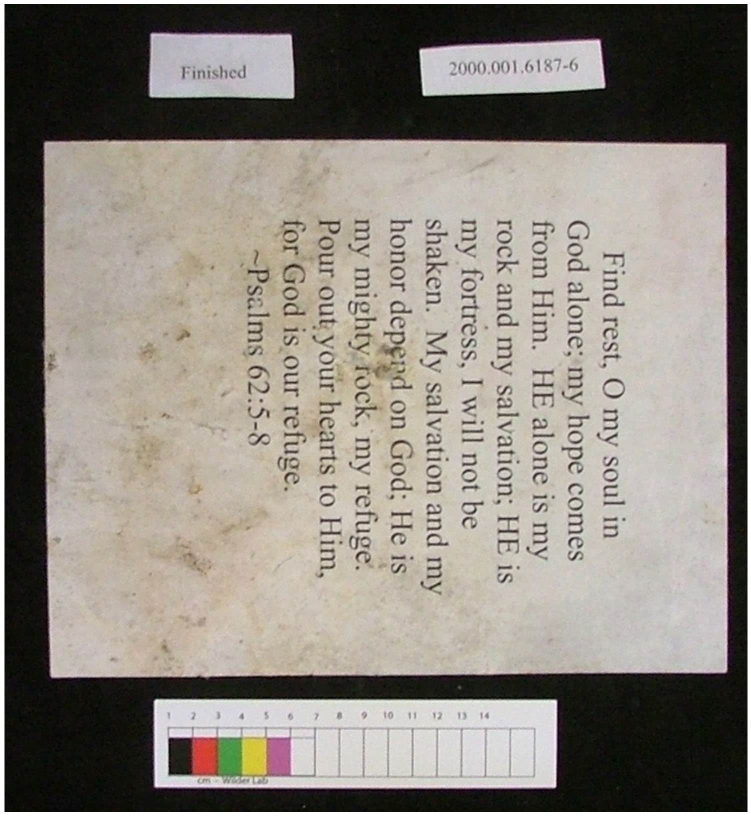
Conclusions:
looks a lot better and feels stronger.
the mends will allow it to be handled

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




Finished
2000.001.6187-6
Find rest, O my soul in God alone; my hope comes from Him. HE alone is my rock and my salvation; HE is my fortress, I will not be shaken. My salvation and my honor depend on God; He is my mighty rock, my refuge. Pour out your hearts to Him, for God is our refuge.
~Psalms 62:5-8
cm – Wilder Lab


Finished
2000.001.6187-6
cm – Wilder Lab

Artifact 2000.001.6187-7

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6187-7 **Initials** ebe

Description and Condition:
"To our fallen Com...." four large note cards taped together with scotch tape
black permenate marker

Must have come with drum sticks

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/SI

Tape not removed

Results: ☐ Excellent ☒ Good ☒ Fair ☐ Poor

Testing:
INk
Lights

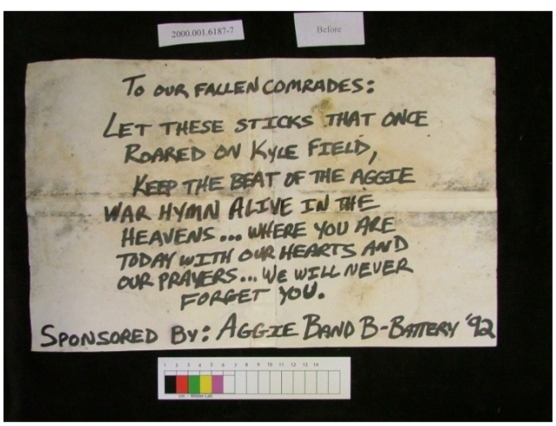
but not MTMS

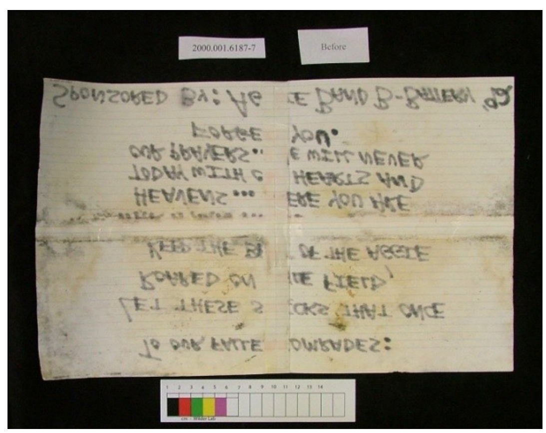
Conclusions:
After talking with Prof. Grider, we decided that it would be best if the tape was left on the item, as it is a discinctive part of the workmanship of the item. With the MTMS Si treatment, it should keep it stable anyway. Unfortunitly, the MTMS caused the perminate ink to run. there fore there is some ghosting of the letters. Other than that it looks good, as it is a lot cleaner and not as yellow.

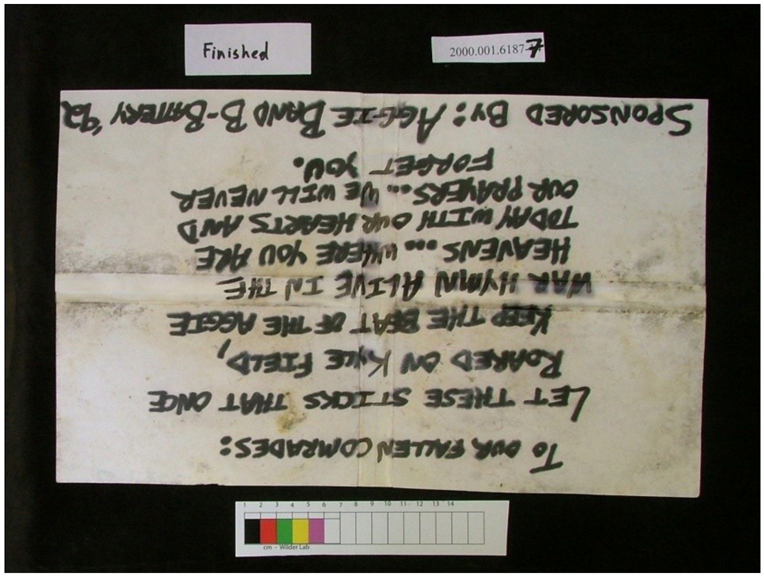
Graphic Record

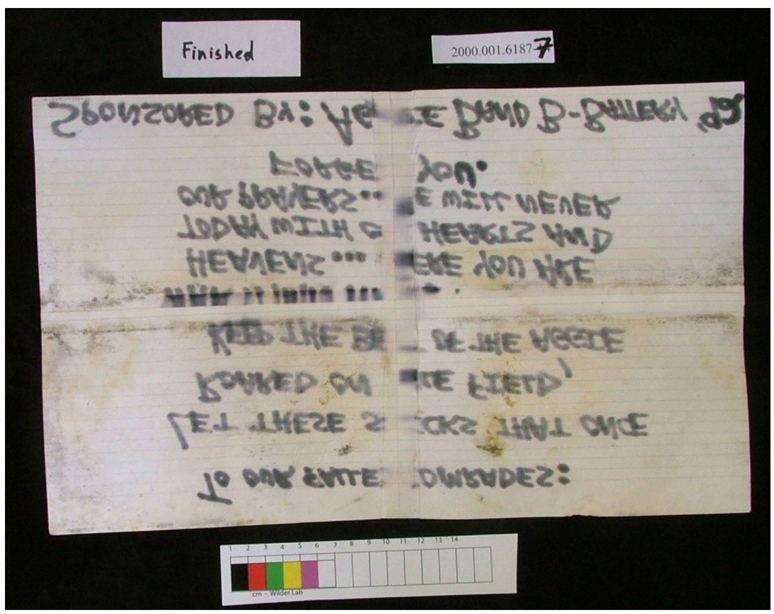
	Before	During	After
Color photo	x		x

Additional Comments:






Finished
2000.001.61877
SPONSORED BY: AGGIE BAND B-BATTERY '02
TO OUR FALLEN COMRADES:
LET THESE STICKS THAT ONCE
ROARED ON KYLE FIELD,
KEEP THE BEAT OF THE AGGIE
WAR HYMN ALIVE IN THE
HEAVENS... WHERE YOU ARE
TODAY WITH OUR HEARTS AND
OUR PRAYERS... WE WILL NEVER
FORGET YOU.


Finished
2000.001.61877

Artifact 2000.001.6187-13

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6187-13 **Initials** ebe

Description and Condition:
8.5 X 11 inches white paper
In plastic acetate? sleeve
ball point ink
"As Aggies we are..."
ball point pen has ink shadow, possibly acidic

Proposed Treatment:
remove from plastic
Wash
flatten
MTMS/Si treatment

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

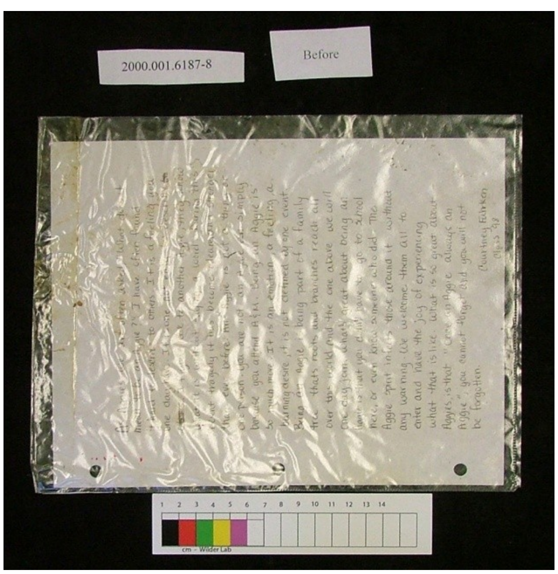
Testing:
ink-not h2o soluble
lights-nothing

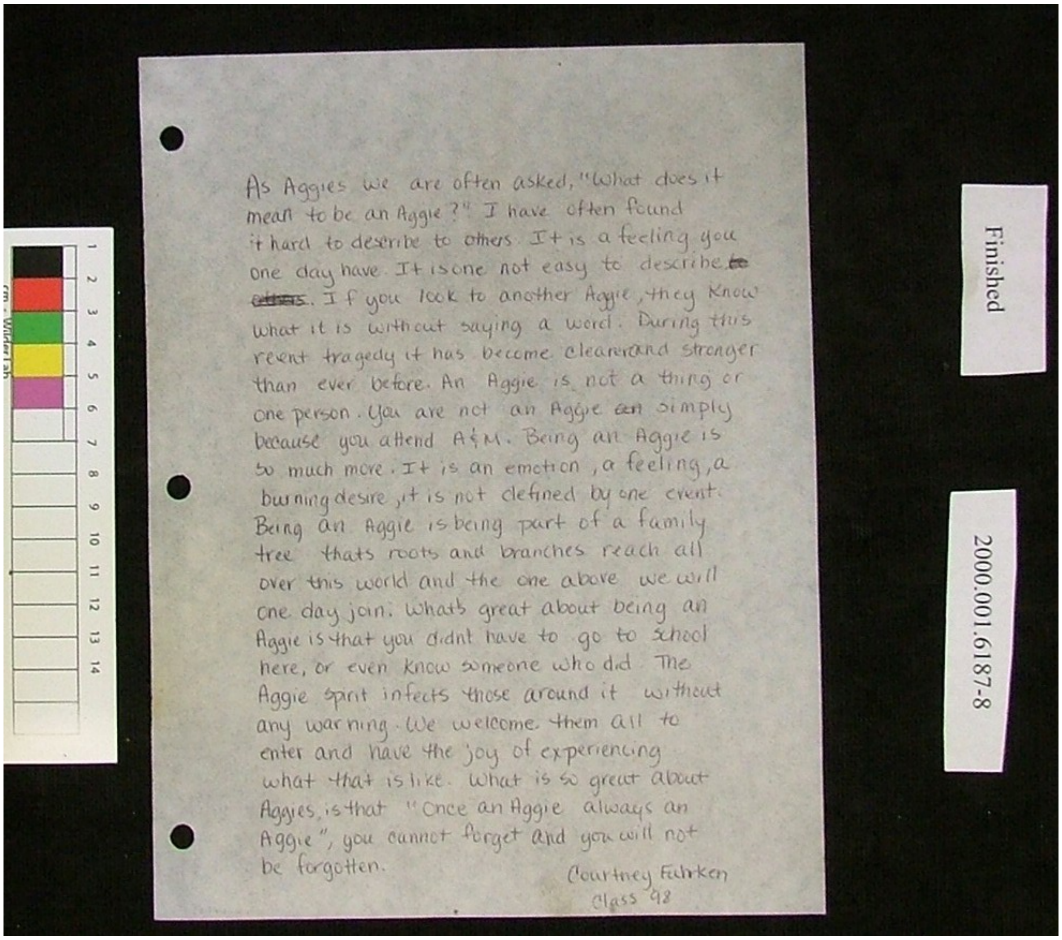
Conclusions:
After the removal of the plastic, surface dirt and mold, the document was washed.
It looks great and the treatment ensures that it will remain strong and not deteriorate.

Graphic Record

	Before	During	After
Color photo	X		X

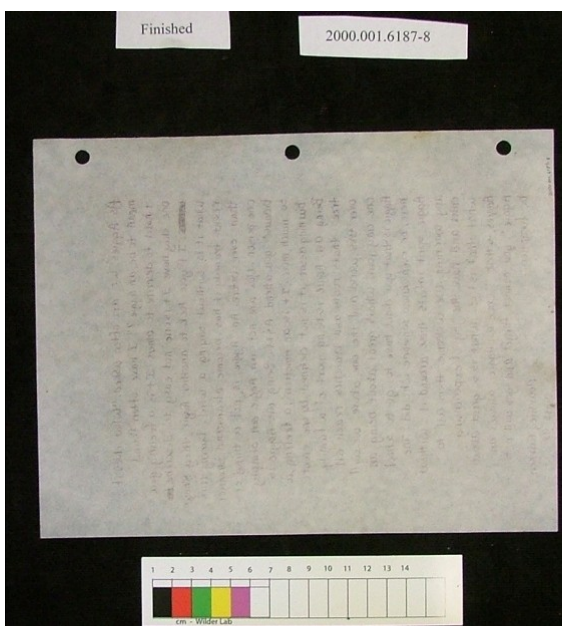
Additional Comments:





As Aggies we are often asked, "What does it mean to be an Aggie?" I have often found it hard to describe to others. It is a feeling you one day have. It is one not easy to describe ~~to~~ ~~others~~. If you look to another Aggie, they know what it is without saying a word. During this recent tragedy it has become clearer and stronger than ever before. An Aggie is not a thing or one person. You are not an Aggie ~~can~~ simply because you attend A&M. Being an Aggie is so much more. It is an emotion, a feeling, a burning desire, it is not defined by one event. Being an Aggie is being part of a family tree thats roots and branches reach all over this world and the one above we will one day join. What's great about being an Aggie is that you didnt have to go to school here, or even know someone who did. The Aggie sprit infects those around it without any warning. We welcome them all to enter and have the joy of experiencing what that is like. What is so great about Aggies, is that "Once an Aggie always an Aggie", you cannot forget and you will not be forgotten.

Courtney Fuhrken
Class 98



Artifact 2000.001.6187-9

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6187-9 **Initials** ebe

Description and Condition:
Computer paper with dot-matrix printing-very faded and unreadable due to dirt and yellowing
in plastic sleve-probably acetate (smells like it)
leaves dirt and mold
oil or candle wax

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Retreat

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
lights
ink

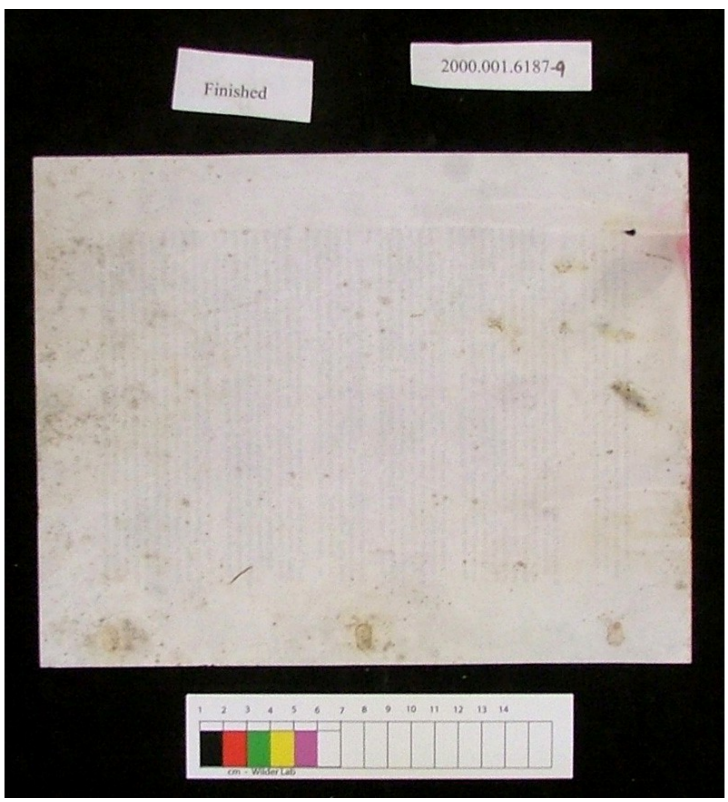
Conclusions:
yellowing gone, can read the printout very faintly
a wrinkle was retained, unfort.
retreatment was necessary, as it showed too much MTMS in the soultion.
looks better after retreatment

Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:


2000.001.6187-4
Finished
cm - Wilder Lab


Finished
2000.001.6187-4
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab

Artifact 2000.001.6187-10

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/5/05 **Artifact No.** 2000.001.6187-10 **Initials** ebe

Description and Condition:
"The Fallen' poem
printer ink very faded and lots of bleed
8.5x11 page white paper
In acetate
yellowed
very wrinkled

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

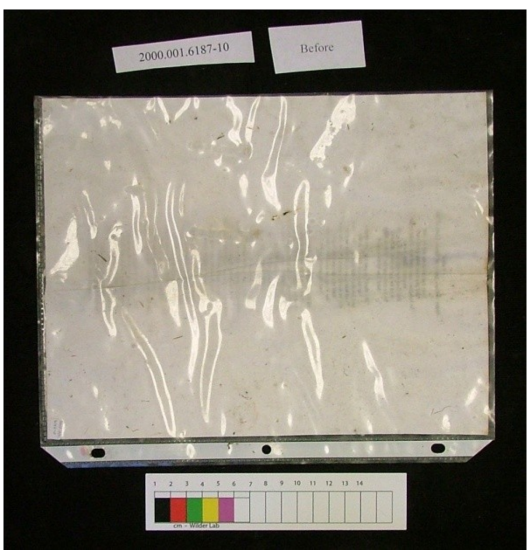
Testing:
ink-no run
lights-nothing

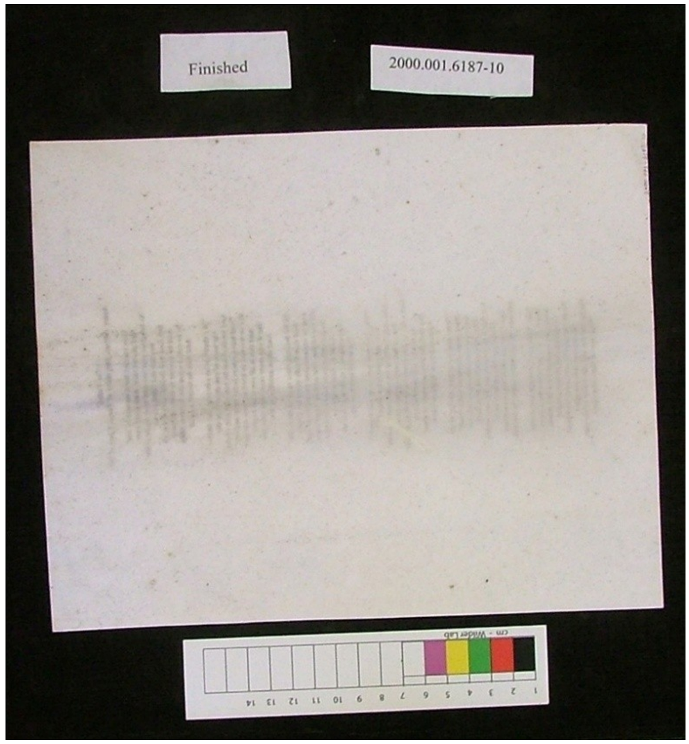
Conclusions:
While the document looks alot better, the center folds/ wrinkles are permenate-possibly repulped in the acetate

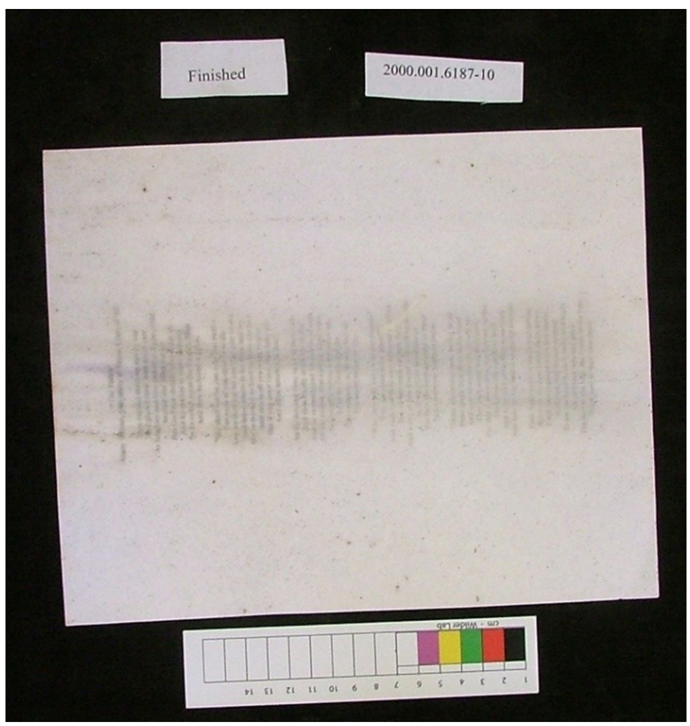
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




Finished
2000.001.6187-10


Finished
2000.001.6187-10

Artifact 2000.001.6187-11

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/5/05 **Artifact No.** 2000.001.6187-11 **Initials** ebe

Description and Condition:
"wishes of hope from Tulane University"
8.5X11 white paper
ball point ink
several holes
several tears
folds
surface dirt
mold
vegetation

Proposed Treatment:
wash
flatten
fill holes
mend tears
MTMS/SI

Retreat with 100% MTMS

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

Testing:
Lights-nothing
ink-secure

Conclusions:
After the first treatment, the pictures really do not do a very good job of demonstrating that this document looks alot better.
Some of the dark spots look darker? Perhaps, some of the MTMS has evaporated, leaving a high concentration of Si oil in the treatment solution

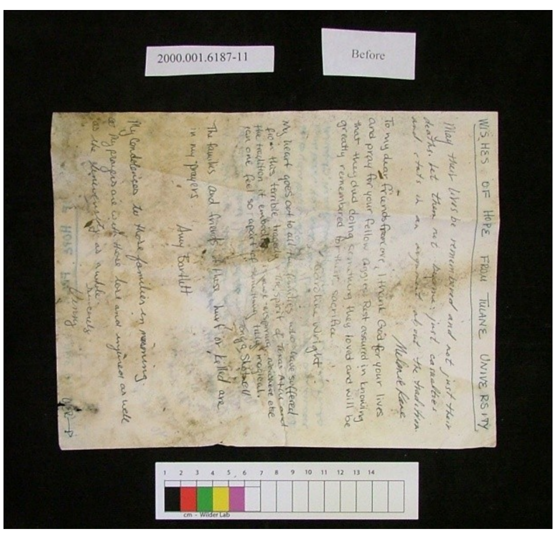
Retreat with 100% MTMS

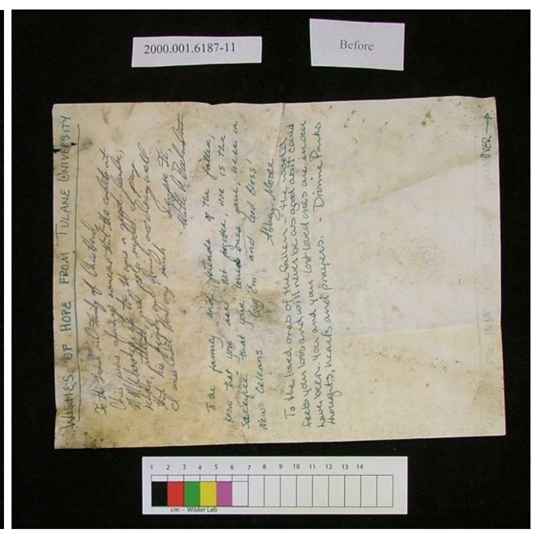
After retreatment, the document is much improved and does not have the translucent quality papers treated with high concentrations of Si oil have. It looks alot better and has more strength

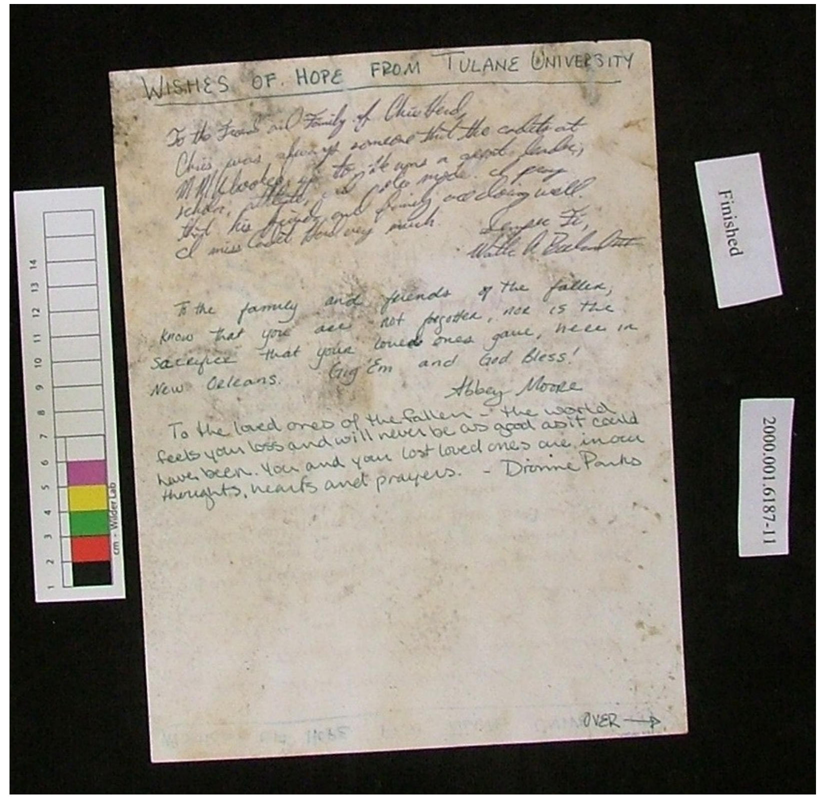
Graphic Record

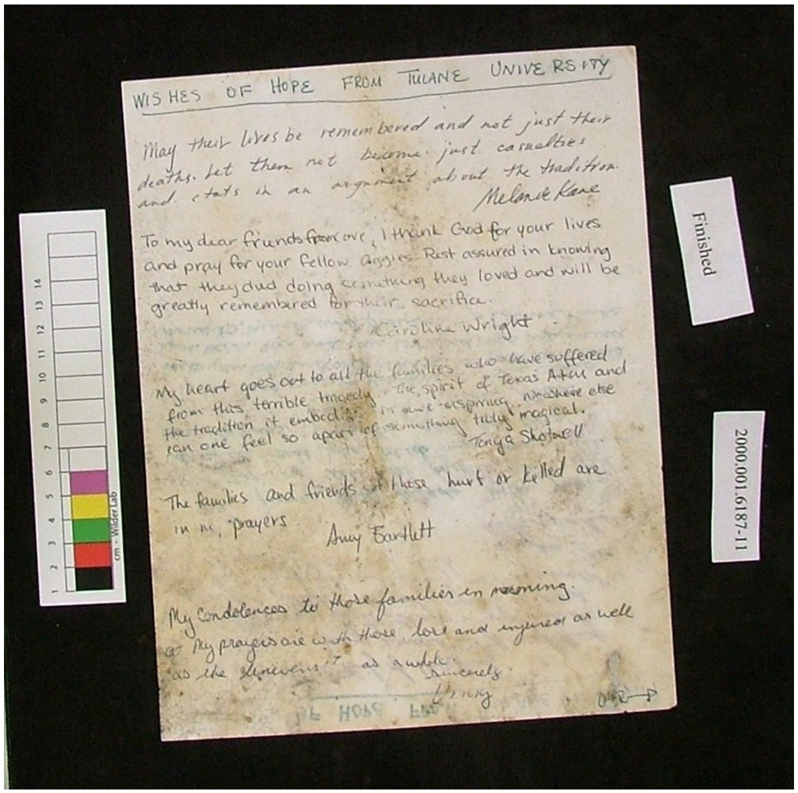
	Before	During	After
Color photo	x	x	x

Additional Comments:






Finished
2000.001.6187-11
WISHES OF HOPE FROM TULANE UNIVERSITY
To the Friends and Family of Chris Heard,
I miss Chris very much.
To the family and friends of the fallen, know that you are not forgotten, nor is the sacrifice that your loved ones gave, here in New Orleans. Gig 'Em and God Bless!
Abbey Moore
To the loved ones of the fallen - the world feels your loss and will never be as good as it could have been. You and your lost loved ones are in our thoughts, hearts and prayers. - Dionne Parks
OVER
cm - Wilder Lab


Finished
2000.001.6187-11
WISHES OF HOPE FROM TULANE UNIVERSITY
May their lives be remembered and not just their deaths. Let them not become just casualties and stats in an argument about the tradition.
Melanie Kane
To my dear friends from over, I thank God for your lives and pray for your fellow Aggies. Rest assured in knowing that they died doing something they loved and will be greatly remembered for their sacrifice.
Caroline Wright
My heart goes out to all the families who have suffered from this terrible tragedy. The spirit of Texas A&M and the tradition it embodies is awe-inspiring. Nowhere else can one feel so apart of something truly magical.
Tonya Shotwell
The families and friends of those hurt or killed are in my prayers.
Amy Bartlett
My condolences to those families in mourning. My prayers are with those lost and injured as well as the University as a whole.
Sincerely
OVER
cm - Wilder Lab

Artifact 2000.001.6187-12

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/25/05 **Artifact No.** 2000.001.6187-12 **Initials** ebe

Description and Condition:
"Dear Fellow Aggies"
8.5x11 white paper with ink-gel or roller ball?-doesnot look like ball point
Three hole pucnh with tears
very week
small voids
surface dirt
mold
folds and tears

Proposed Treatment:
Wash
flatten
mend
flatten
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

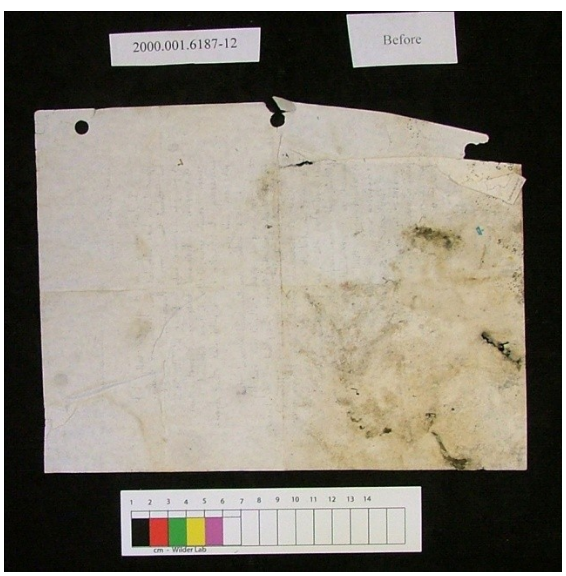
Testing:
ink
lights

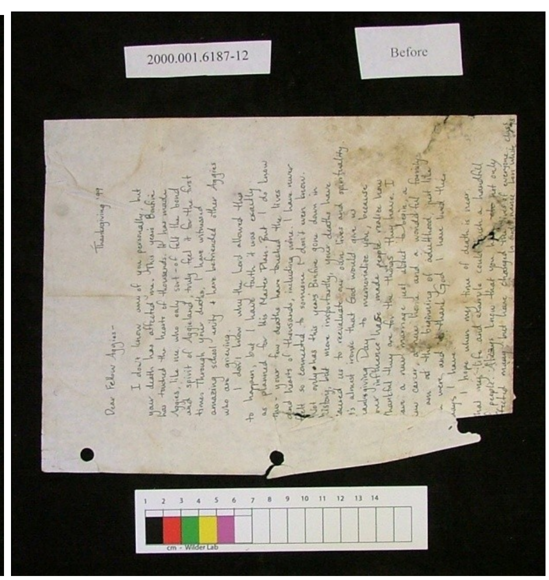
Conclusions:
It was very brittle to start with, but after treatment it is very pliable
It looks a lot better as well and can be handled easily.

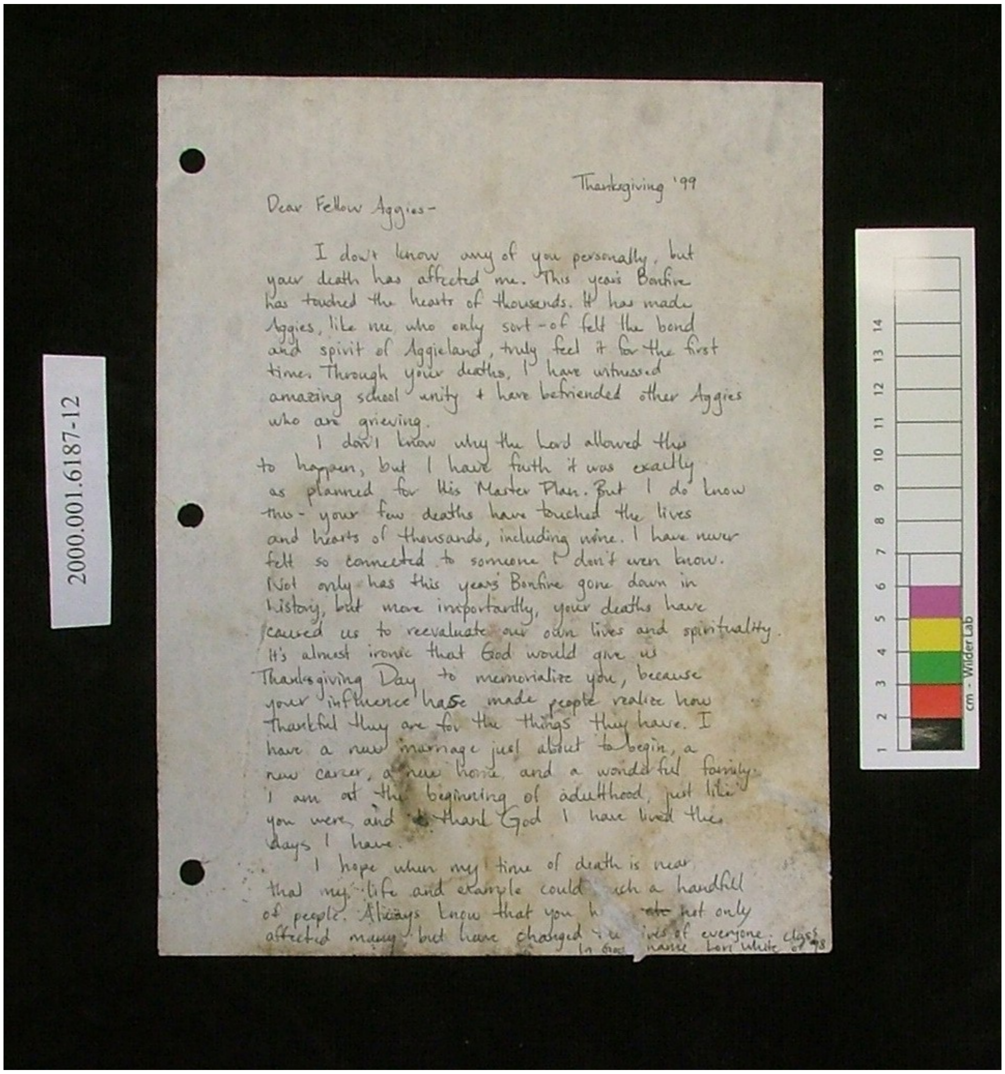
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:







Thanksgiving '99

Dear Fellow Aggies-

I don't know any of you personally, but your death has affected me. This year's Bonfire has touched the hearts of thousands. It has made Aggies, like me who only sort-of felt the bond and spirit of Aggieland, truly feel it for the first time. Through your deaths, I have witnessed amazing school unity + have befriended other Aggies who are grieving.

I don't know why the Lord allowed this to happen, but I have faith it was exactly as planned for His Master Plan. But I do know this - your few deaths have touched the lives and hearts of thousands, including mine. I have never felt so connected to someone I don't even know. Not only has this years' Bonfire gone down in history, but more importantly, your deaths have caused us to reevaluate our own lives and spirituality. It's almost ironic that God would give us Thanksgiving Day to memorialize you, because your influence ha~~s~~e made people realize how thankful they are for the things they have. I have a new marriage just about to begin, a new career, a new home and a wonderful family. I am at the beginning of adulthood, just like you were, and ~~I~~ thank God I have lived the days I have.

I hope when my time of death is near that my life and example could [illegible] a handfull of people. Always know that you h[illegible] ~~ate~~ not only affected many but have changed [illegible] lives of everyone. class

In God's name Lori White of '98

Artifact 2000.001.6187-

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 20000.001.6187-13 **Initials** ebe

Description and Condition:
Laminated cardstock
black printer ink
lots of surface dirt
candle wax
No before pictures

Proposed Treatment:
It was decided that it would not be necessary to remove the laminate.
It was washed

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

Testing:
lights-no reaction

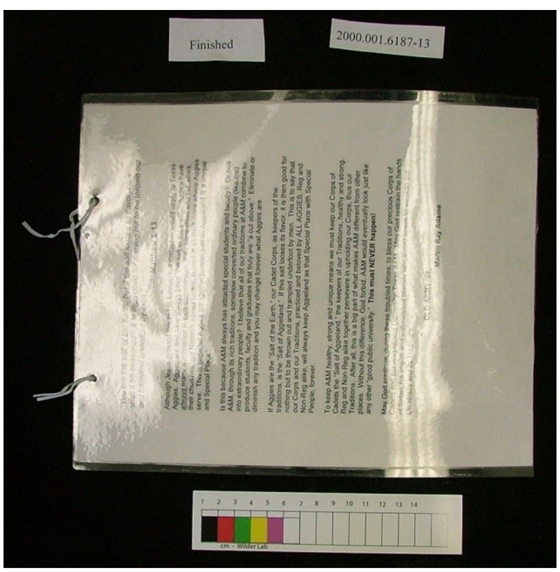
Conclusions:
looks as good as the day it was made
cleaning was all it needed

Graphic Record

	Before	During	After
Color photo			x

Additional Comments:

13



Artifact 2000.001.6187-14

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 20000.001.6187-14 **Initials** ebe

Description and Condition:
Laminated cardstock
black printer ink
lots of surface dirt
candle wax
No before pictures

Proposed Treatment:
It was decided that it would not be necessary to remove the laminate.
It was washed

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

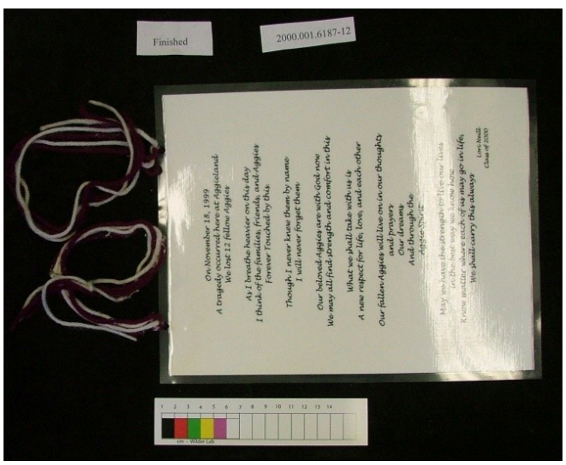
Testing:
lights-no reaction

Conclusions:
looks as good as the day it was made
cleaning was all it needed

Graphic Record

	Before	During	After
Color photo			x

Additional Comments:



Artifact 2000.001.6187-15

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6187-15 **Initials** ebe

Description and Condition:
"Bonfire Victims" sealed letter envelope
lots of surface dirt
mold
vegetation
dirt and water logged
candle wax oils?

Proposed Treatment:
mechanically clean
wash
mend
MTMS/Si

Retreat letter

Results: ☐ Excellent ☐ Good ☒ Fair ☐ Poor

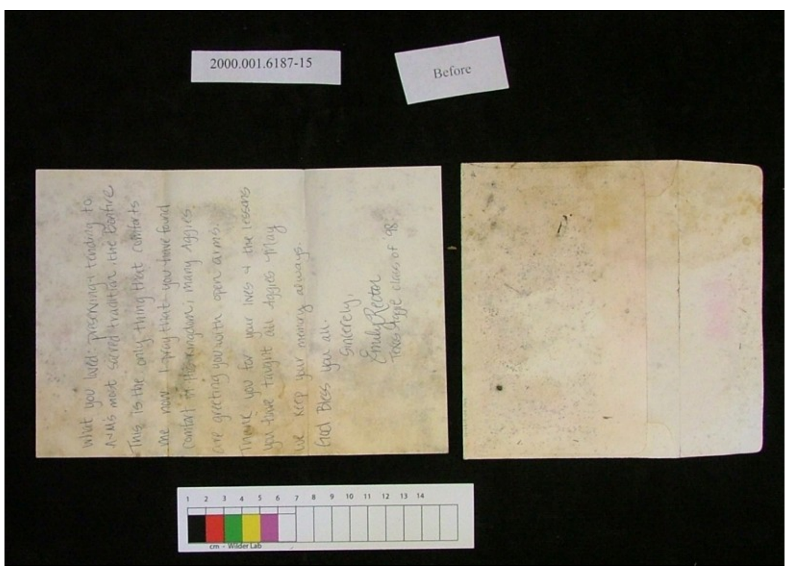
Testing:
Ink-h2o safe
lights, nothing

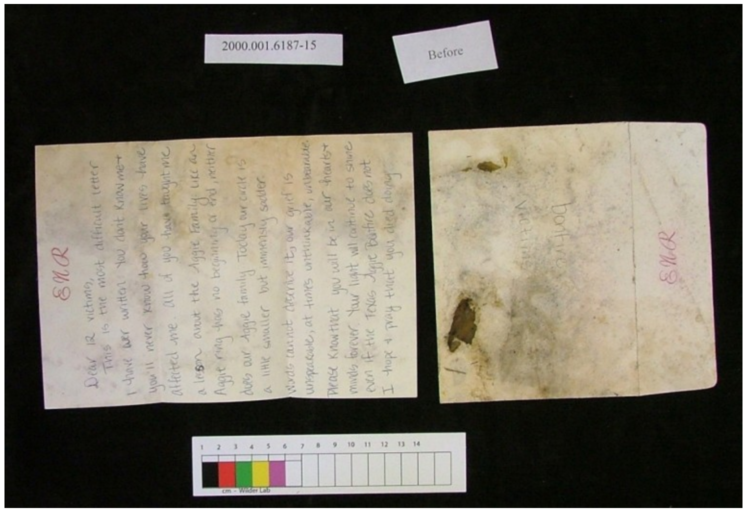
Conclusions:
The ink on one side can be seen on both side as a result of the MTMS/ Si treatment. While the letter is stronger and the mold is dead, it is a shame that some of the ascetic beauty of the letter has been lost due to the ghosting of the letters from the reverse. This should not have happened if it had gone in to a better solution initially.

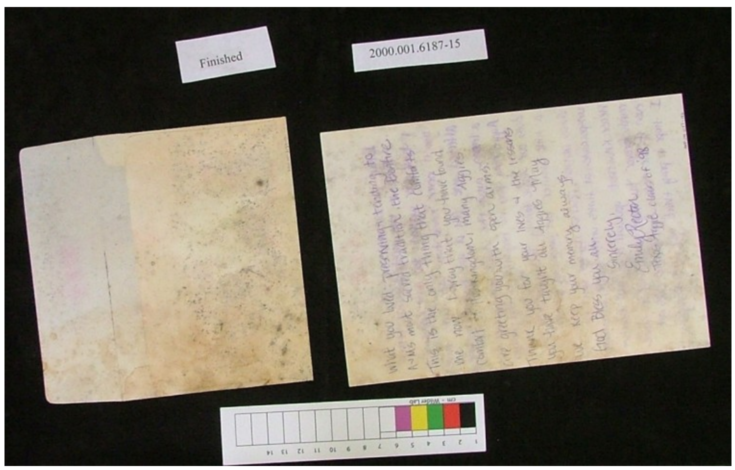
Graphic Record

	Before	During	After
Color photo	x	x	x

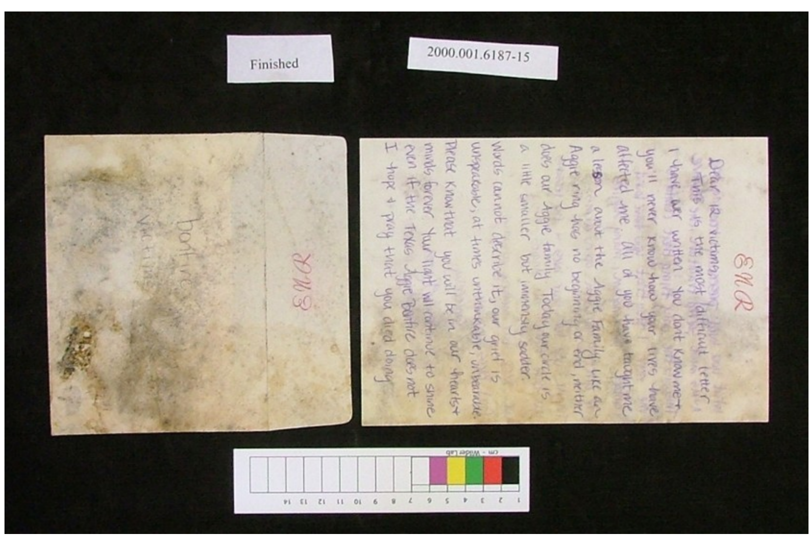
Additional Comments:



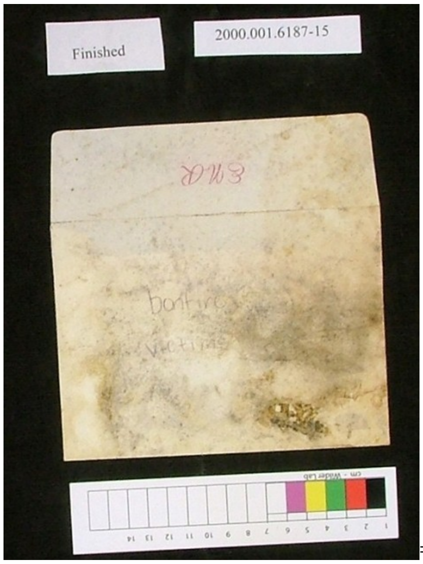


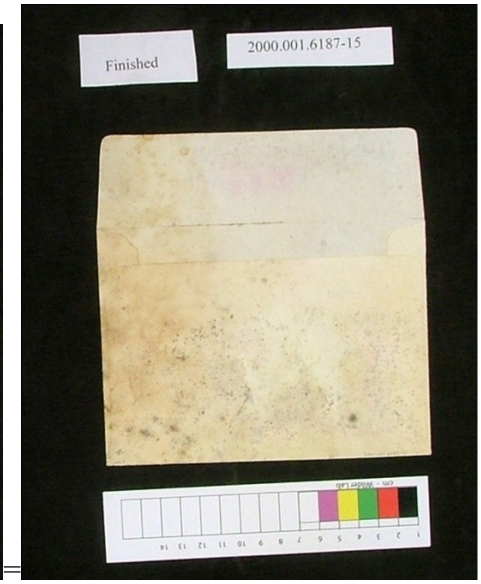


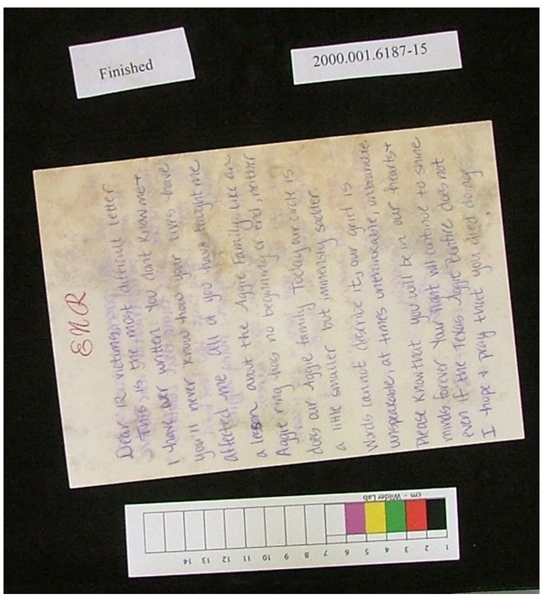
In Progress before retreatment

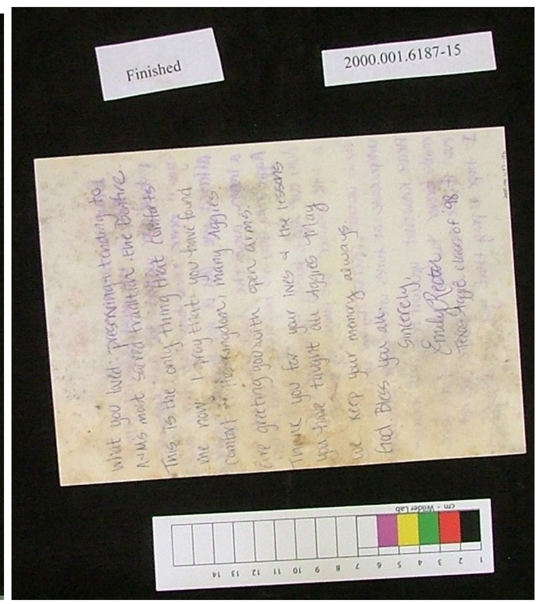


In Progress before retreatment


Finished
2000.001.6187-15
ENR
bonfire
victims


Finished
2000.001.6187-15


Finished
2000.001.6187-15
ENR
Dear IR victims,
This is the most difficult letter
I have ever written. You don't know me +
you'll never know how your lives have
affected me. All of you have taught me
a lesson about the Aggie Family. Like an
Aggie ring has no beginning or end, neither
does our Aggie family. Today our circle is
a little smaller but immensely sadder.
Words cannot describe it, our grief is
unspeakable, at times unthinkable, unbearable.
Please know that you will be in our hearts +
minds forever. Your light will continue to shine
even if the Texas Aggie Bonfire does not.
I hope + pray that you died doing


Finished
2000.001.6187-15
what you loved: preserving + tending to
A+M's most sacred tradition, the Bonfire.
This is the only thing that comforts
me now. I pray that you have found
comfort in His kingdom; many Aggies
are greeting you with open arms.
Thank you for your lives + the lessons
you have taught all Aggies. May
we keep your memory always.
God Bless you all.
Sincerely,
Emily Rector
Texas Aggie class of '98

Artifact 2000.001.6187-16

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/05/05 **Artifact No.** 2000.001.6187-16 **Initials** ebe

Description and Condition:
3x4 white card
Perminate black marker in spanish
saftey pin
nothing attached
mold
surface dirt
odd orange stain
turning brown at edges

Proposed Treatment:
wash
flatten
MTMS/Si

Retreat with MTMS

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

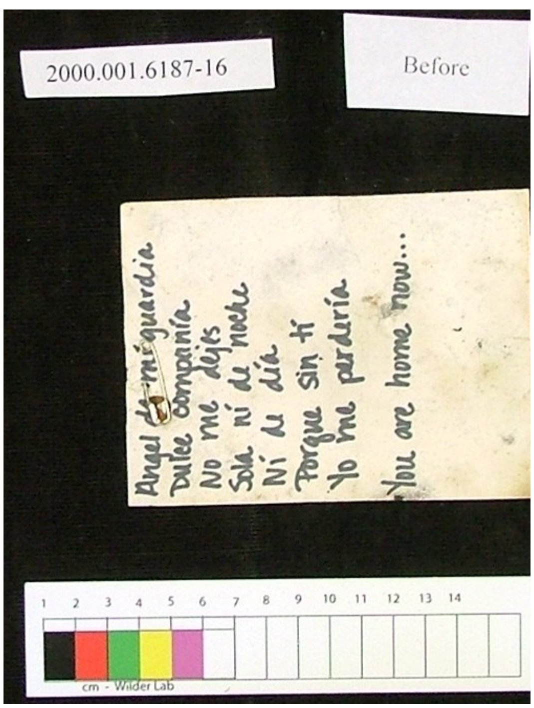
Testing:
Lights-nothing
ink- h2o safe

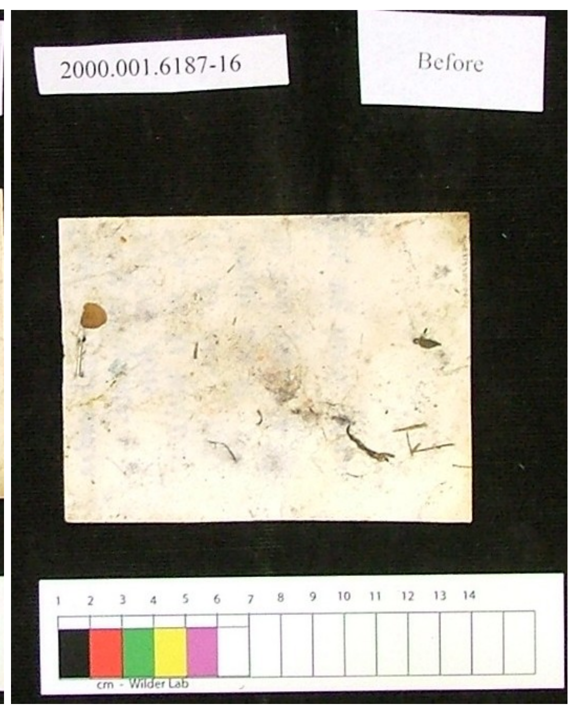
Conclusions:
This card looks alot better after cleaning
After the first MTMS/SI treatment, it was decided that there was too much Si in the solution, due to the evaporation of MTMS from the solution. After retreatment with 100% MTMS its appearance is much improved

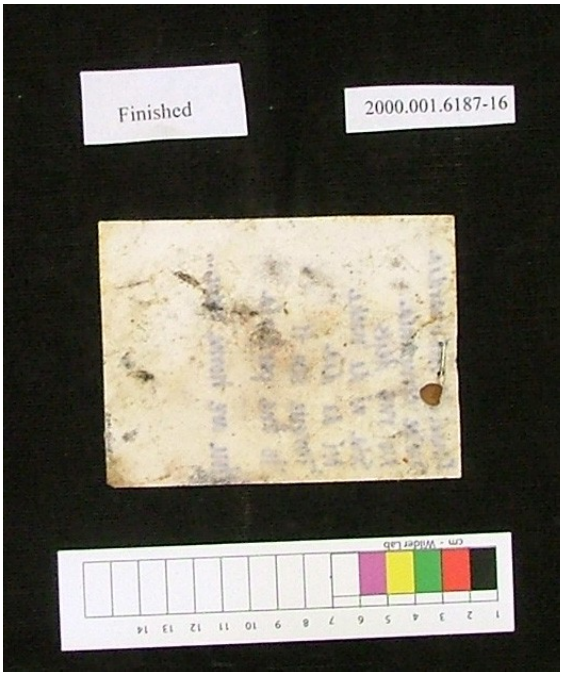
Graphic Record

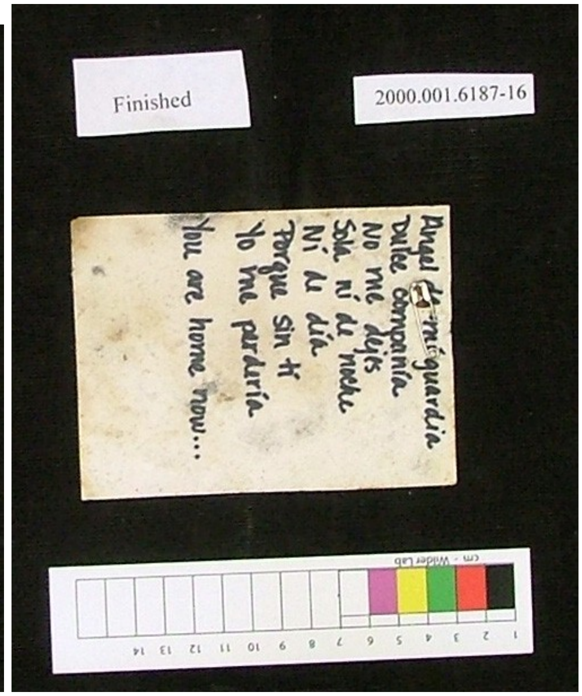
	Before	During	After
Color photo	x	X	X

Additional Comments:

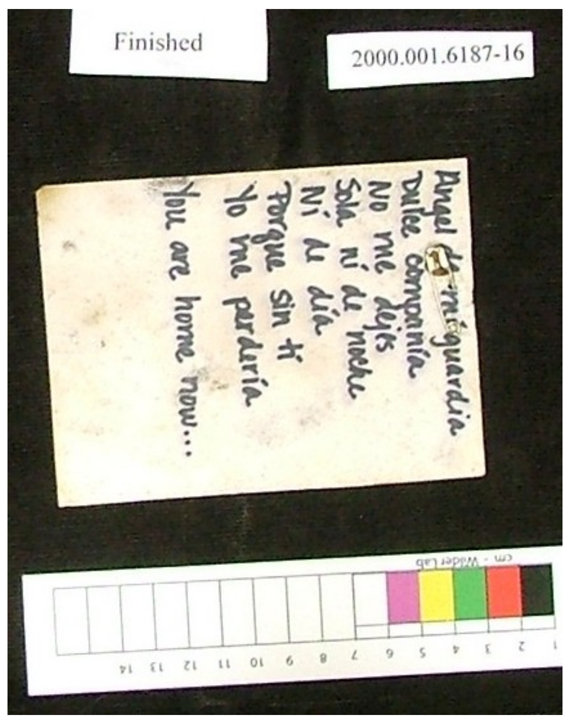








In progress before retreatment



Artifact 2000.001.6187-17

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/17/05 **Artifact No.** 2000.001.6187-17 **Initials** ebe

Description and Condition:
Envelope for a flower card

Surface dirt and mold
badly folded

Proposed Treatment:
Brush
Wash
Flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

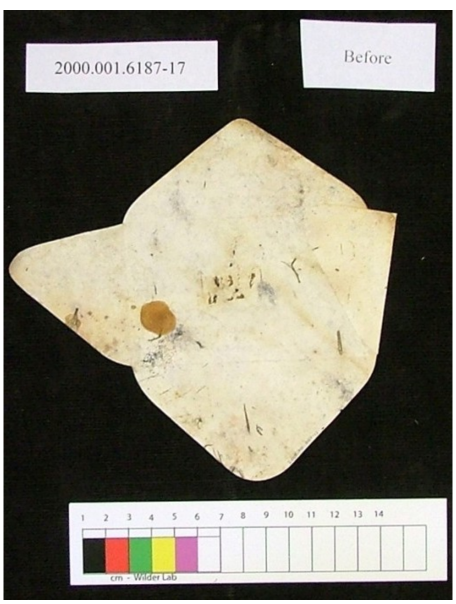
Testing:
lights-very reflective with the UVA, Nothing distinctive
Ink-not h2o soluble

Conclusions:
While it doesn't look that much better, it's strength has improved
The old folds came out, but can be returned to the original shape

Graphic Record

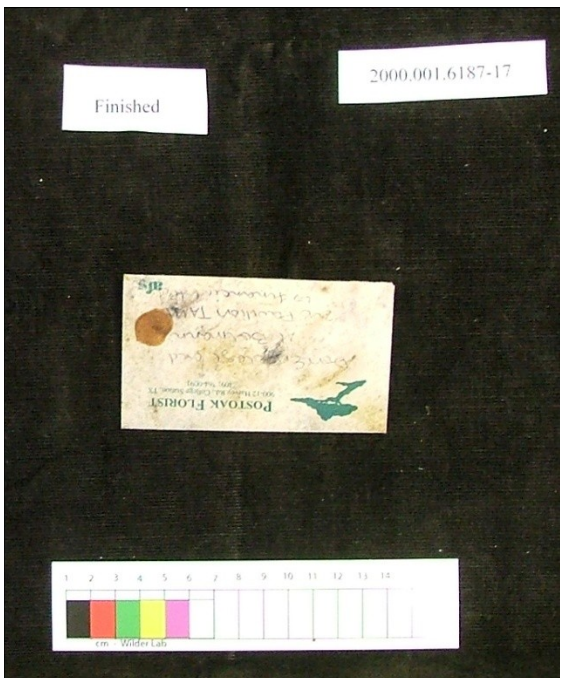
	Before	During	After
Color photo	X		X

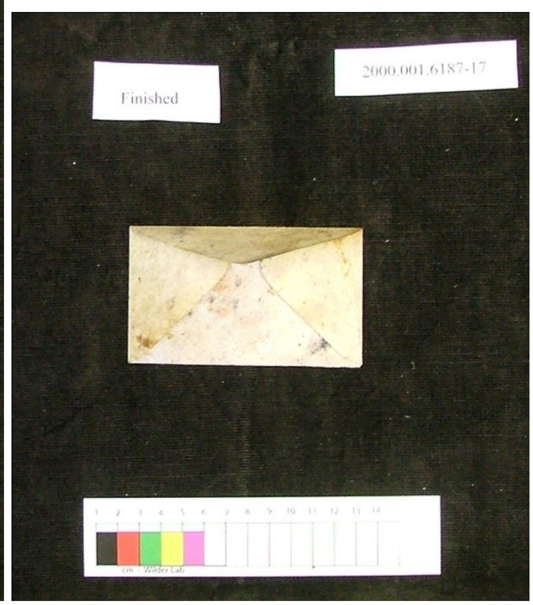
Additional Comments:




Finished
2000.001.6187-17


Finished
2000.001.6187-17
POSTOAK FLORIST


Finished
2000.001.6187-17
POSTOAK FLORIST


Finished
2000.001.6187-17

Artifact 2000.001.6187-18

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6187-18 **Initials** ebe

Description and Condition:
5X7 note card with yellow ribbon with straight pin
ball point ink
Badly folded
lots of surface dirt and mold

Proposed Treatment:
Brush
wash
Mtms/si treatment
mend

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

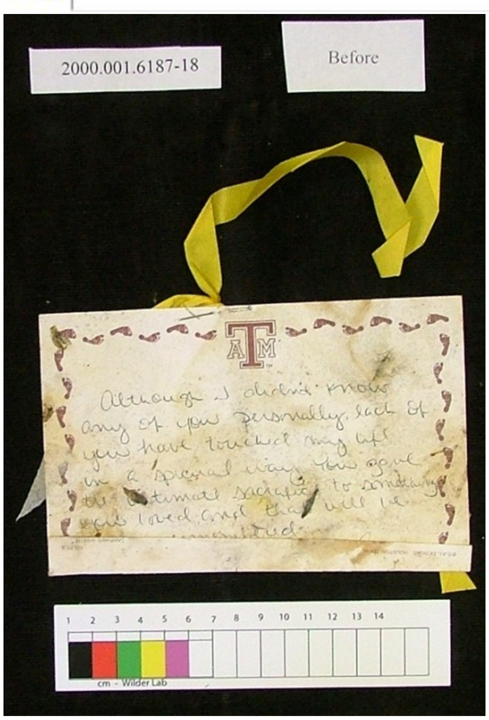
Testing:
ink-not h2o solvent
lights-UVA reactive, but no particular designs

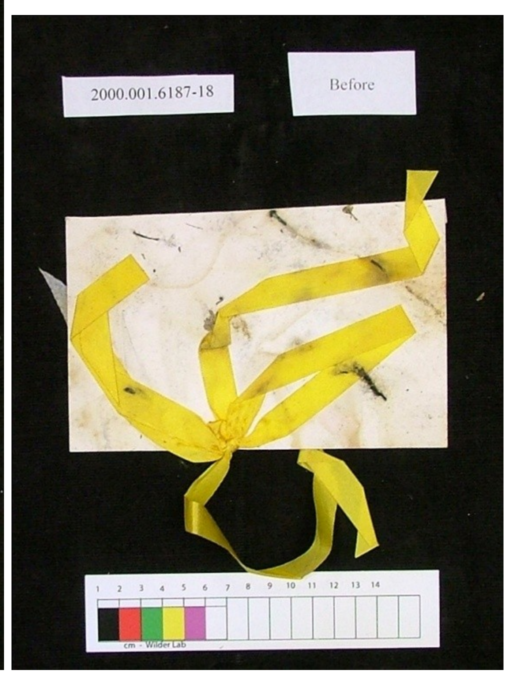
Conclusions:
It looks alot better after cleaning and flattening
still, some staining did remain
the Treatment has improved its strength

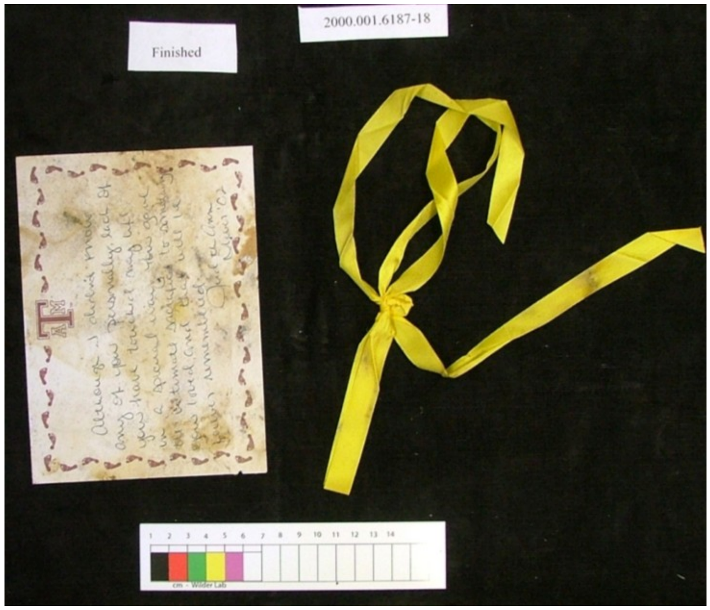
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:






Finished
2000.001.6187-18
cm – Wilder Lab


Finished
2000.001.6187-18
cm – Wilder Lab

Artifact
2000.001.6188

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/20/05 **Artifact No.** 2000.001.6188 **Initials** ebe

Description and Condition:
small pamphlet on glossy paper
2x3.5

Proposed Treatment:
attempt to open dry
Attempt to open wet
treat with MTMS/Si

Results: ☐ Excellent ☐ Good ☒ Fair ☐ Poor

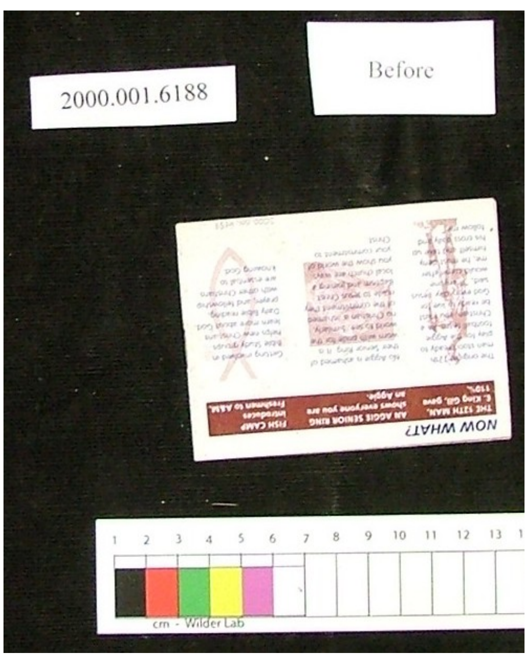
Testing:
lights
ink

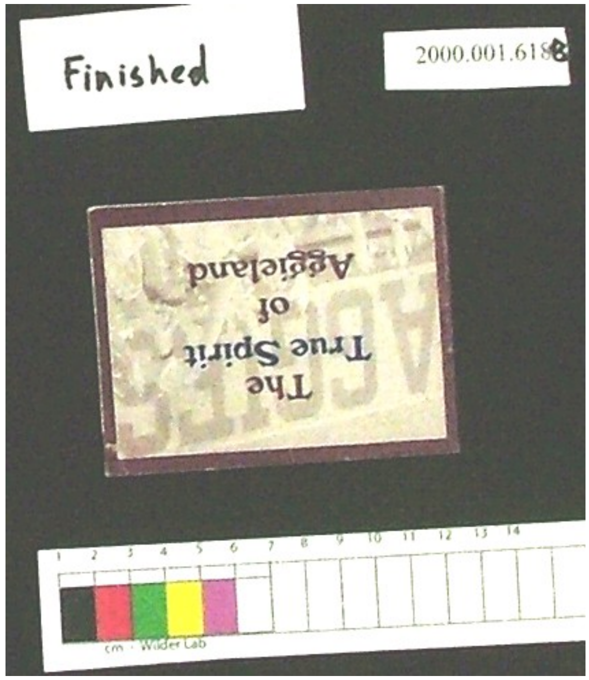
Conclusions:
Never could get it open, but it si treated

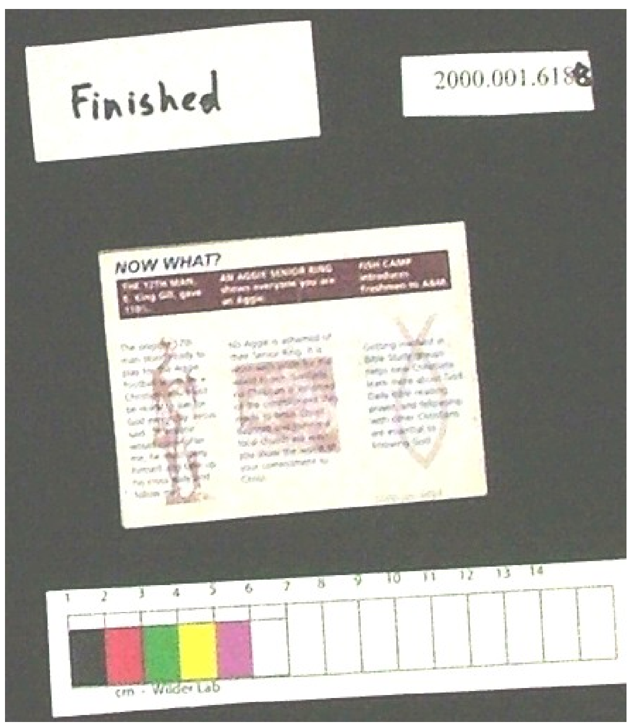
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




Finished
2000.001.618
The
True Spirit
of
Aggieland
cm · Wilder Lab


Finished
2000.001.618
NOW WHAT?
cm · Wilder Lab

Artifact 2000.001.6189

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/13/05 **Artifact No.** 2000.001.6189 **Initials** ebe

Description and Condition:
6.24X3 inch paper
Media=ball point pen
mold and surface dirt
candle wax
several folds

Proposed Treatment:
wash
flatten
MTMS/si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
Ink- not soluble in H2o
Light shoued nothing distince

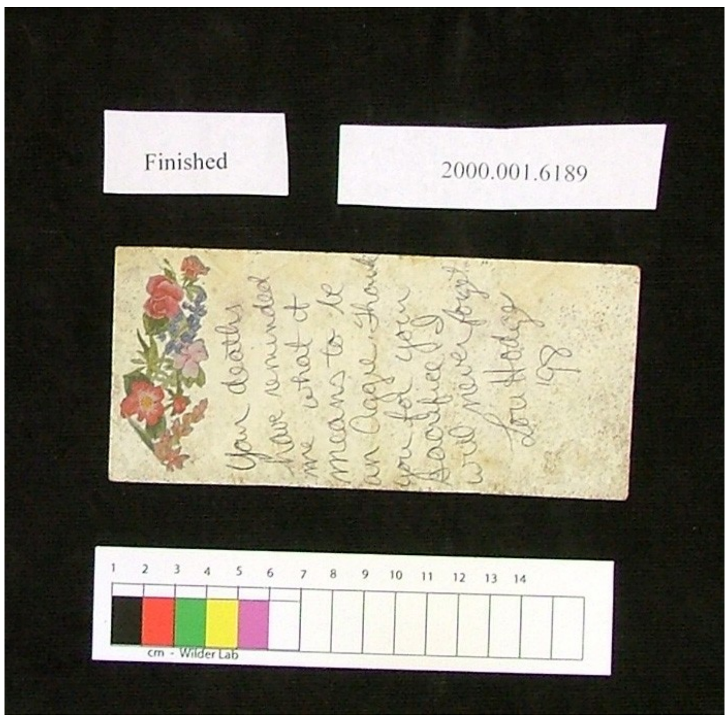
Conclusions:
Looks better and the strength is increased

Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:


Finished
2000.001.6189
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab


Finished
2000.001.6189
Your deaths have reminded me what it means to be an Aggie. Thank you for your sacrifice. I'll never forget.
Lou Hodge
'98
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab

Artifact 2000.001.6199

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6190 **Initials** ebe

Description and Condition:
"we love Jeremy"
construction paper with black perminate ink
five "photos" pasted to paper, with pitting from degredation
Photos are probably computer printed on semi-gloss paper
in acetated sleve
lots of mold and surface dirt

Proposed Treatment:
wash
flatten
paste photos to their orignal places
MTMS/Si treatment

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

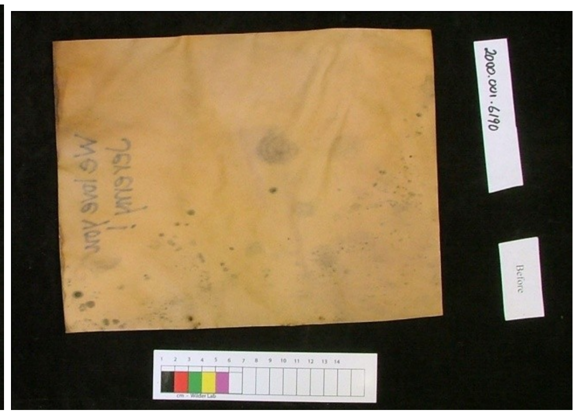
Testing:
light
ink

Conclusions:
Good to be out of acetate
looks better with photos reattached
seems very secure with MTMS/si treatment
While the pictures are not as glossy anymore, the pitting is not obvious

Graphic Record

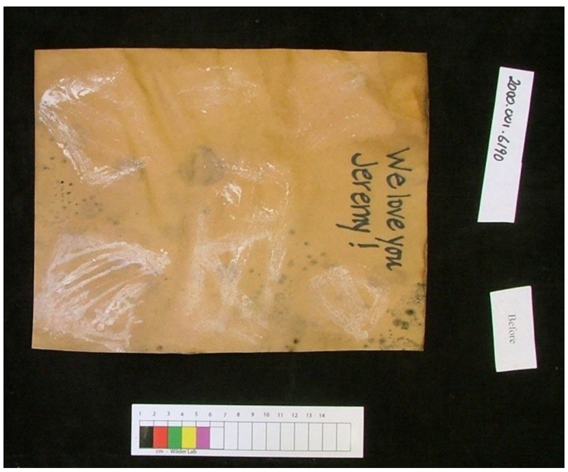
	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.6190
Before


2000.001.6190
Before


We love you
Jeremy!
2000.001.6190
Before


2000.001.6190
Before


Finished
2000.001.6190


We love you
Jeremy !
2000.001.6190
Finished
cm - Wilder Lab

Artifact 2000.001.6191

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/18/05 **Artifact No.** 2000.001.6191 **Initials** ebe

Description and Condition:
3x5 Envelope with a sticker of an angel with a letter inside.
lots of surface dirt and mold

Letter-5x7 stationary with 3 folds
pencil letter to "Tim"
mold and staining

Proposed Treatment:
brush envelop
open envelope
wash both
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

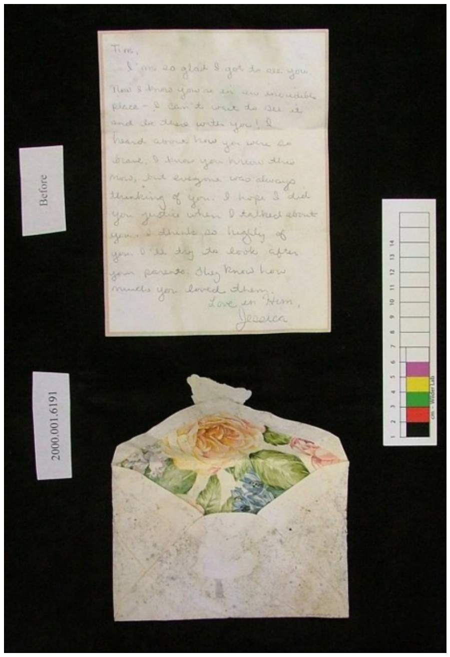
Testing:
Ink-ethanol and h2o
Light-nothing of note

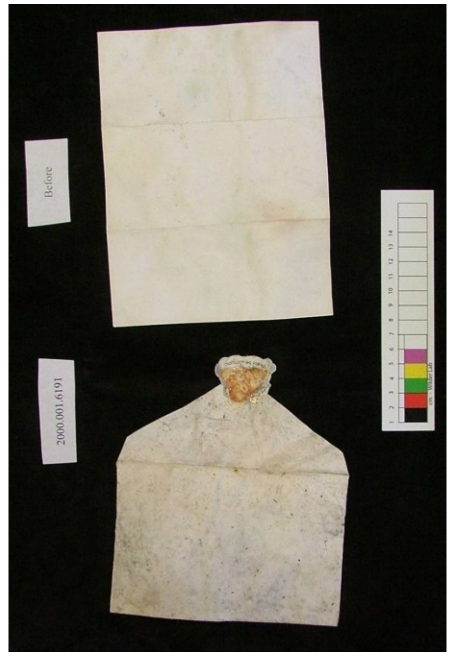
Conclusions:
looks much better after washing
It has more strength after treatment

Graphic Record

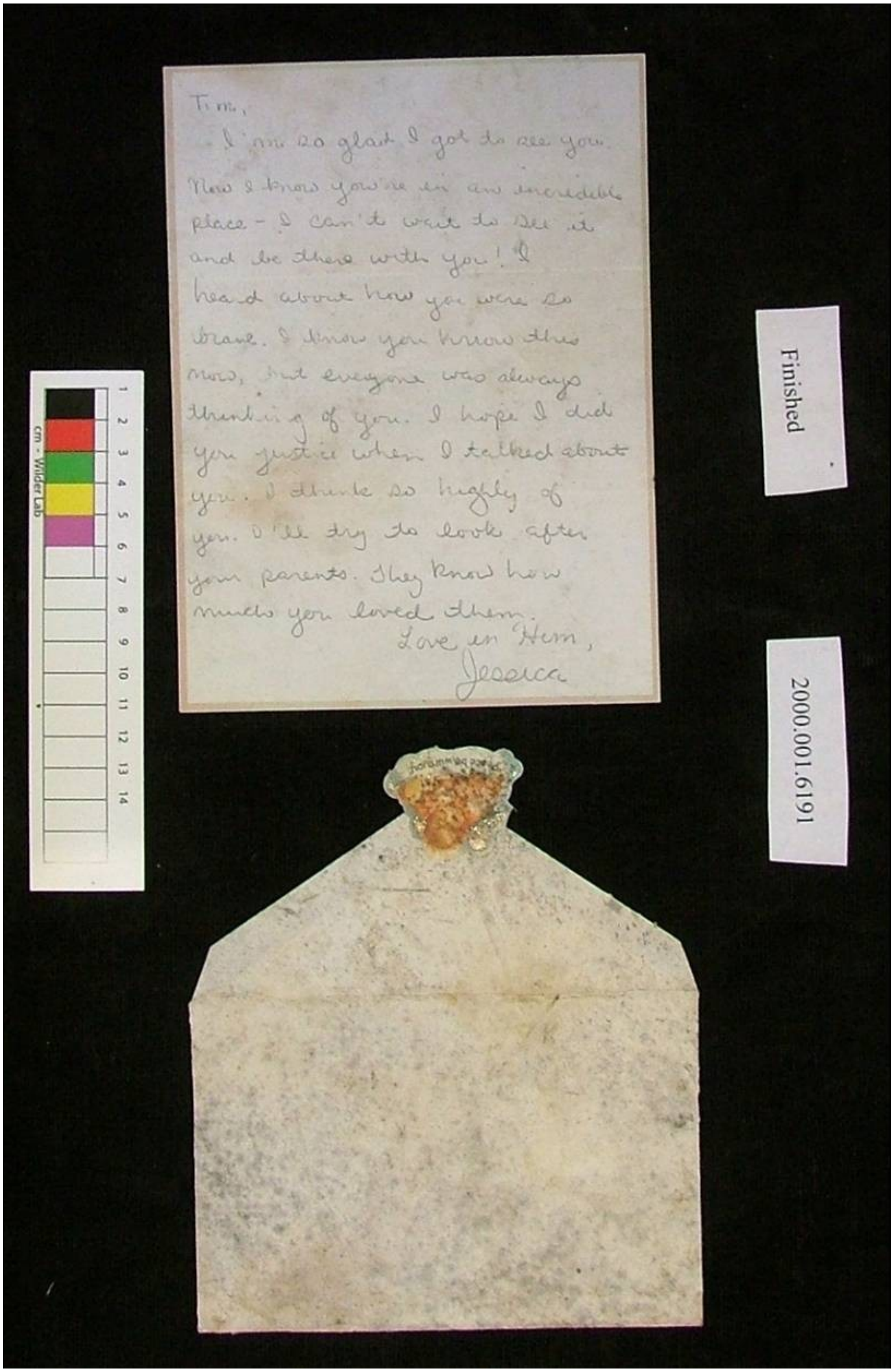
Color photo Before During After

Additional Comments:


Before
2000.001.6191
Tim,
I'm so glad I got to see you.
Now I know you're in an incredible
place - I can't wait to see it
and be there with you! I
heard about how you were so
brave. I know you knew this
now, but everyone was always
thinking of you. I hope I did
you justice when I talked about
you. I think so highly of
you. I'll try to look after
your parents. They know how
much you loved them.
Love in Him,
Jessica


Before
2000.001.6191


Finished
2000.001.6191
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab


Tim,

I'm so glad I got to see you. Now I know you're in an incredible place - I can't wait to see it and be there with you! I heard about how you were so brave. I know you know this now, but everyone was always thinking of you. I hope I did you justice when I talked about you. I think so highly of you. I'll try to look after your parents. They know how much you loved them.

Love in Him,

Jessica

Artifact 2000.001.6192-1

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/5/05 **Artifact No.** 2000.001.6192-1 **Initials** ebe

Description and Condition:
folded
surface dirt
mold
vegetation
8.5x11 white paper
black ink

Proposed Treatment:
unfold-humidify
wash
flatten
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

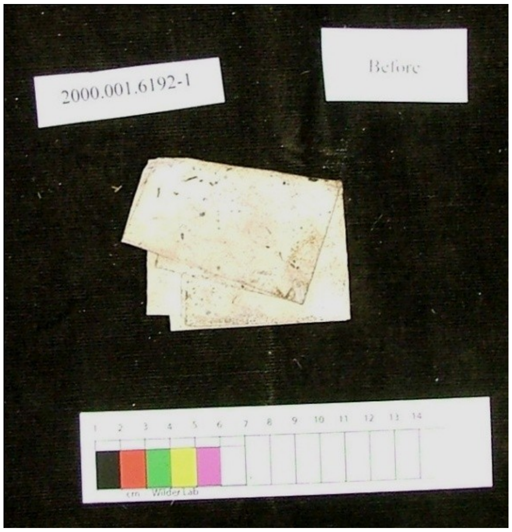
Testing:
ink-safe
light-nothing

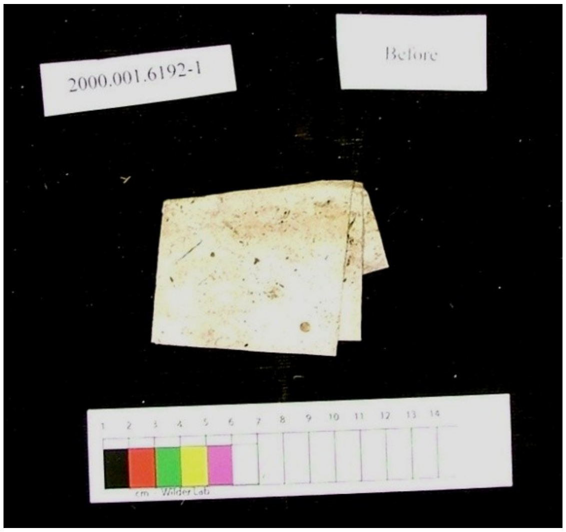
Conclusions:
clean-no dirt. well-flattened
much stronger

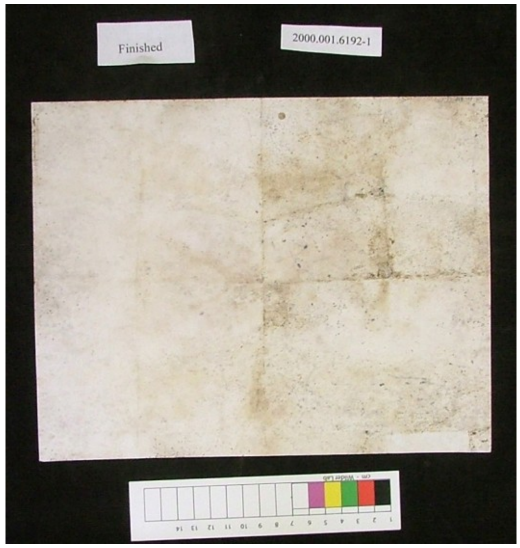
Graphic Record

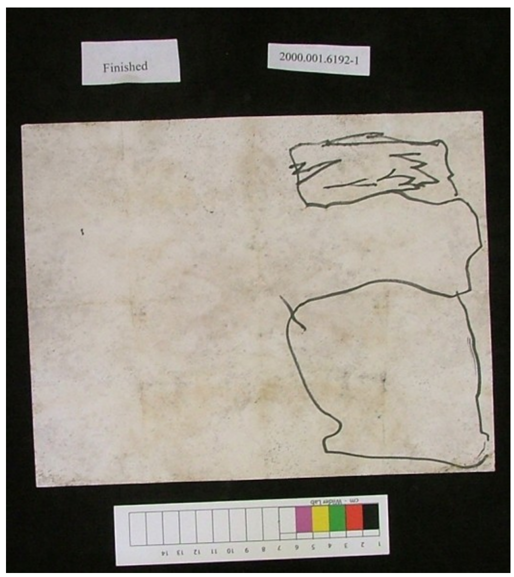
	Before	During	After
Color photo	x		x

Additional Comments:






Finished
2000.001.6192-1


Finished
2000.001.6192-1

Artifact 2000.001.6192-2,3

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6192-2 **Initials** ebe

Description and Condition:
3x8 cars stock? paper with A&M scenes on it
Rosary taped to it
2 types of ink writing
small tear on bottom
dirt
mold

Proposed Treatment:
mechanically clean
remove tape
wash
flatten
MTMS/Si

no mend

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

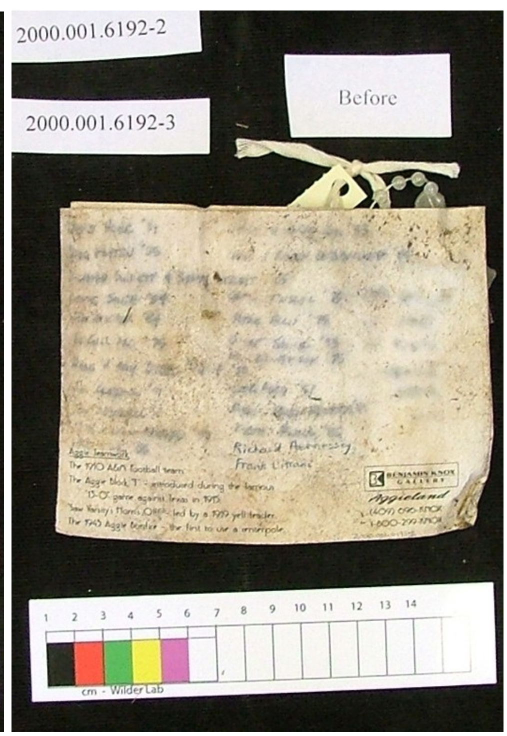
Testing:
ink
lights

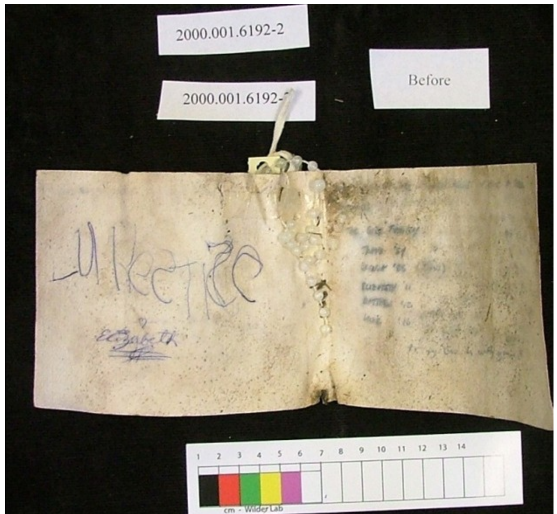
Conclusions:
The tape had to be removed, since it would not be flattened well. During the removal, the layer of paper directly underneath it was removed partially. the dirt was well-ground in and was only possible to remove some
the tear was not repaired, as it did not seem likely to continue to tear.

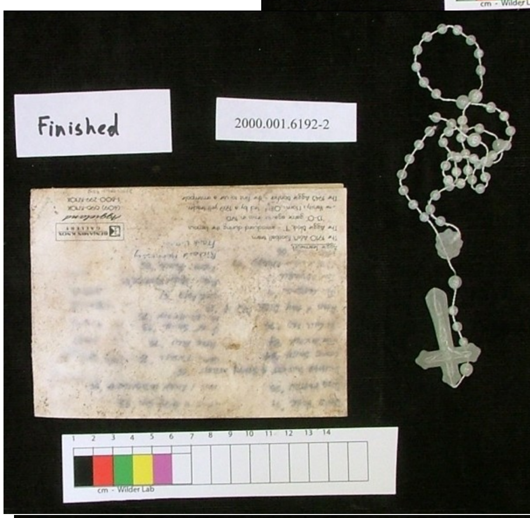
Graphic Record

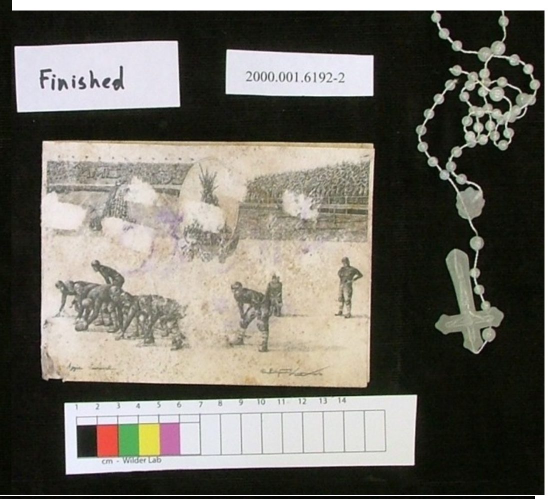
	Before	During	After
Color photo	x		x

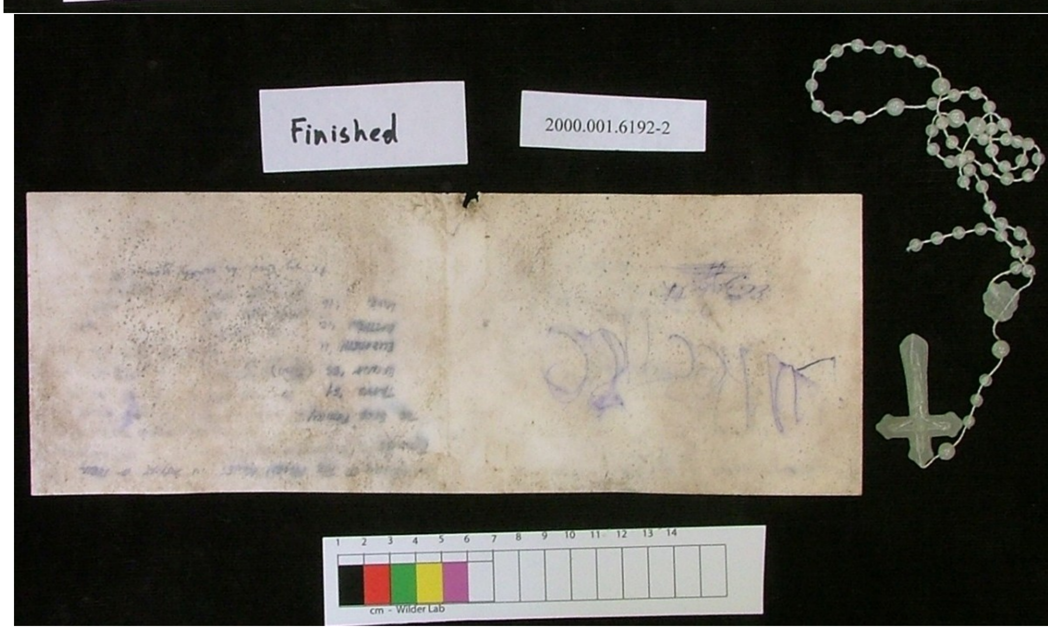
Additional Comments:




2000.001.6192-2
2000.001.6192-2
Before


Finished
2000.001.6192-2


Finished
2000.001.6192-2


Finished
2000.001.6192-2

Artifact 2000.001.6192-4

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6192-4 **Initials** ebe

Description and Condition:
8.5x11 sheet of white paper
no writing
oil or candle wax
several voids and fragile areas

Proposed Treatment:
mechanically clean
wash
flatten
mend
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

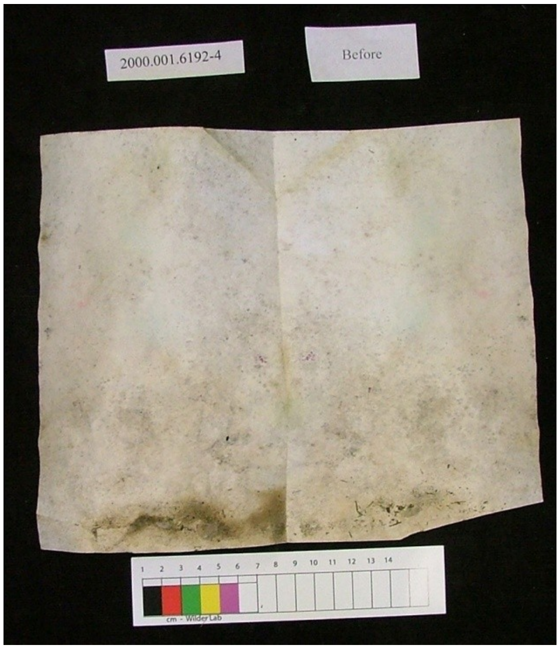
Testing:
lights

Conclusions:
looks better
much more flxible and better since mends

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6192-4
Before
cm - Wilder Lab


Finished
2000.001.6192-4
cm - Wilder Lab


Finished
2000.001.6192-4
cm - Wilder Lab

Artifact 2000.001.6192-5

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/5/05 **Artifact No.** 2000.001.6192-5 **Initials** ebe

Description and Condition:
construction paper card-green
I am so sorry... in green gel? pen
tears with small void
lots of surface dirt
mold

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

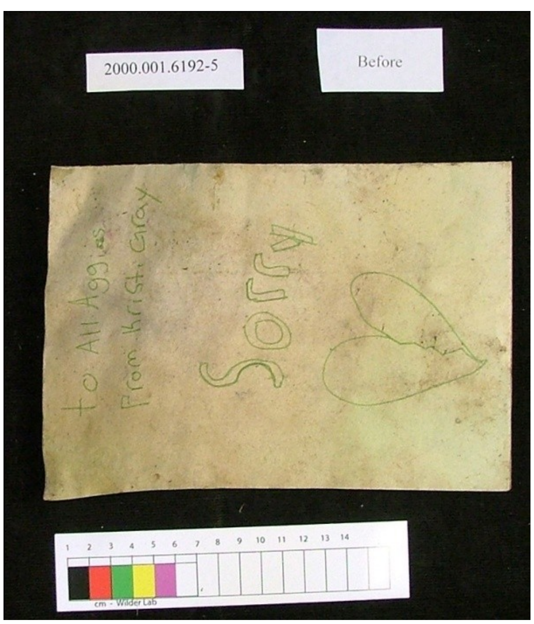
Testing:
ink
lights

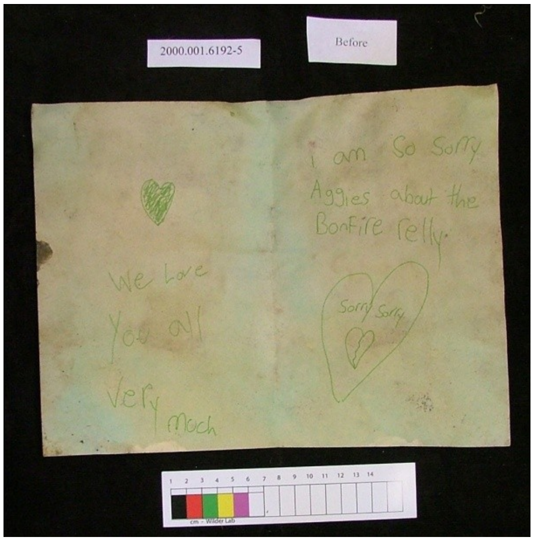
Conclusions:
looks lots better and is much stronger

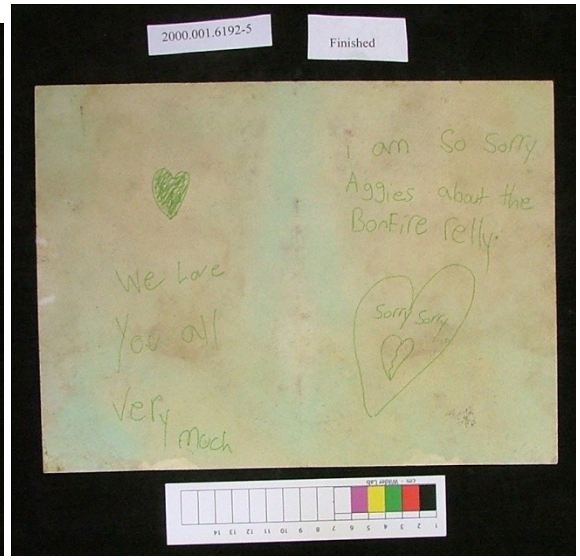
Graphic Record

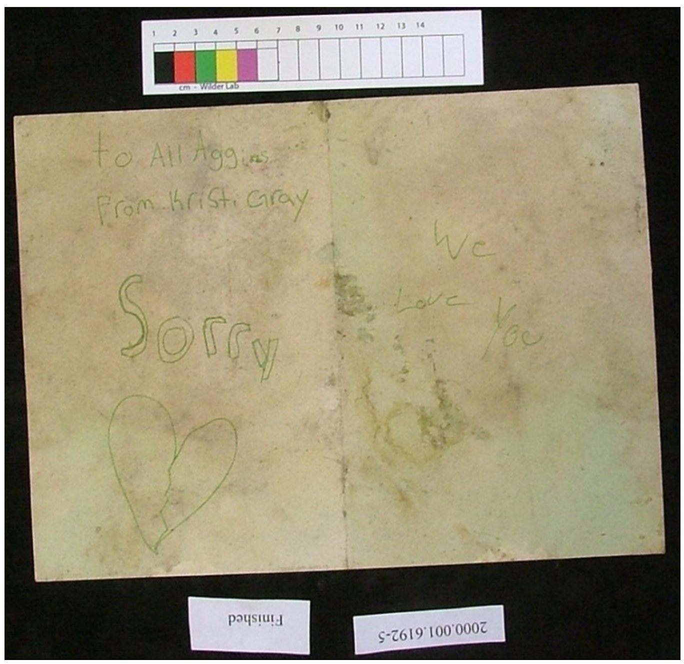
	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.6192-5
Before
i am So Sorry Aggies about the Bonfire relly.
We Love You all Very Moch
Sorry Sorry
cm – Wilder Lab


2000.001.6192-5
Finished
i am So Sorry Aggies about the Bonfire relly.
We Love You all Very Moch
Sorry Sorry


cm – Wilder Lab
to All Aggies
From Kristi Gray
Sorry
We Love You
Finished
2000.001.6192-5

Artifact 2000.001.6192-6

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/05/05 **Artifact No.** 2000.001.6192-6 **Initials** ebe

Description and Condition:
construction paper card
green ink, black ink, crayon, red pencil
lots of vegetation
mold
surface dirt
several tears
voids
odd white residue-could be mold but probably something else

Proposed Treatment:
mechanically clean
wash
flatten
mend and fill
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

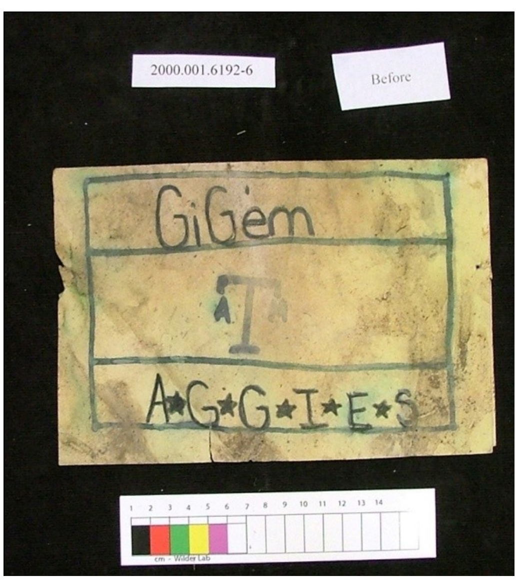
Conclusions:
look so much better after cleaning and washing.
since the mend paper is not color coordinated to the paper, it seems a bit obvious, but it is necessary to the handling of the object. Choose to use paper instead of just glue as the fibers in the artifact are not very stable, and may not hold well with just glue

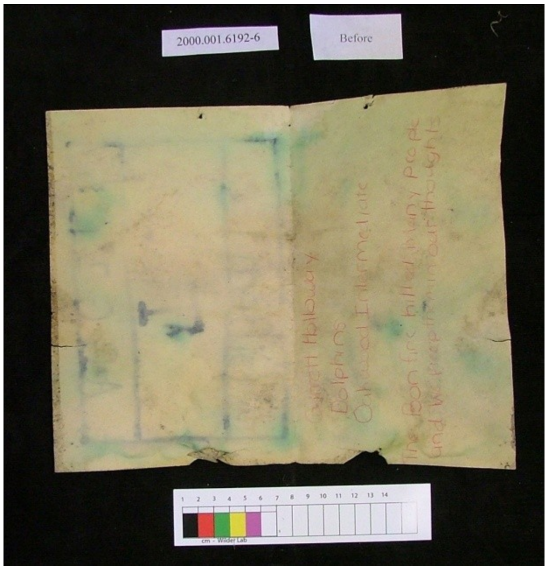
treatment added strength

Graphic Record

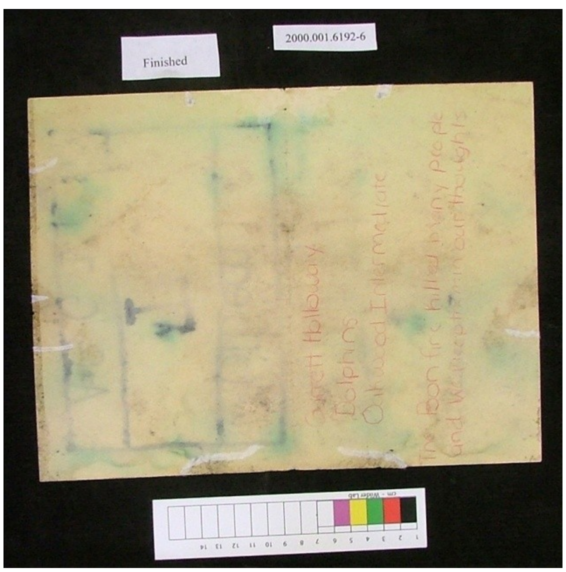
	Before	During	After
Color photo	x		x

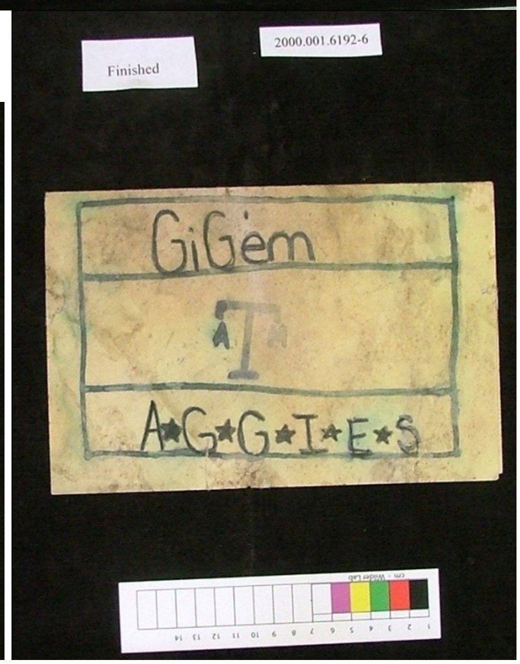
Additional Comments:




2000.001.6192-6
Before


Finished
2000.001.6192-6
GiG'em
A★G★G★I★E★S


Finished
2000.001.6192-6


Finished
2000.001.6192-6
GiG'em
A★G★G★I★E★S

Artifact 2000.001.6193-1

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/20/05 **Artifact No.** 2000.001.6193-1 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Jeremy Frampton"
maroon card stock
mold
wrinkles
In acetate

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

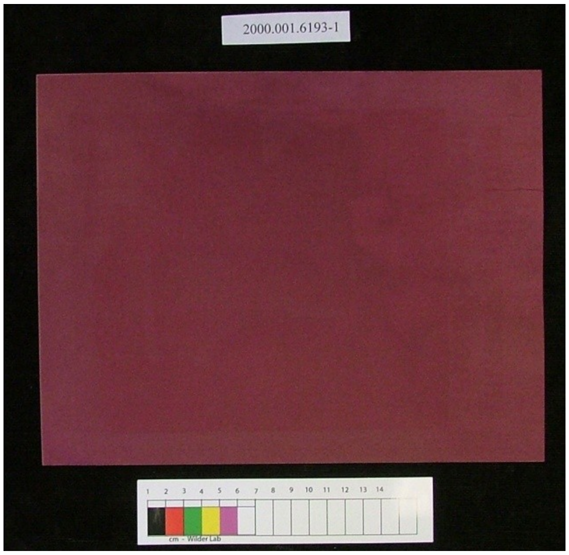
Testing:
ink
Light

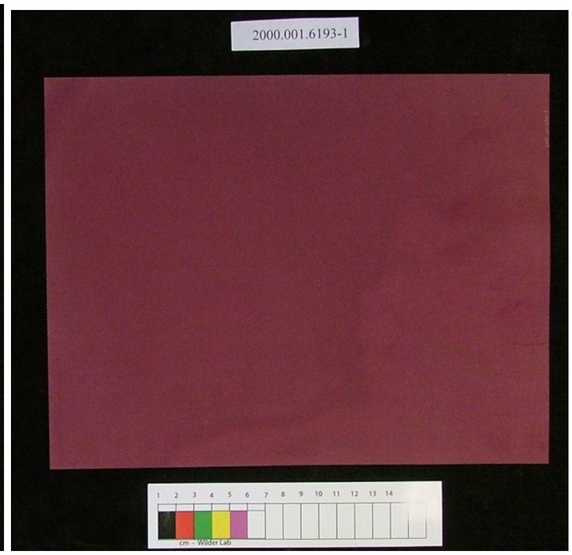
Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles

Graphic Record

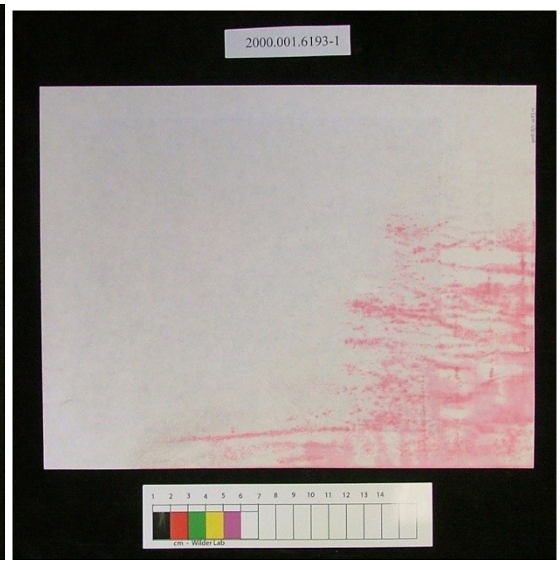
	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6193-1


2000.001.6193-1


2000.001.6193-1
Jeremy Frampton
Turlock. California


2000.001.6193-1

Artifact 2000.001.6193-2

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-2 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Christopher..."
2 maroon card stock
mold
wrinkles
In acetate

Proposed Treatment:
wash
flatten

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
Light

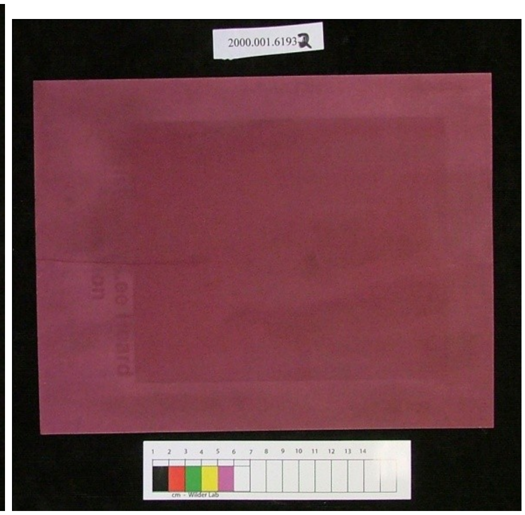
Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles. It was decided that MTMS/Si was not necessary for its conservation

Graphic Record

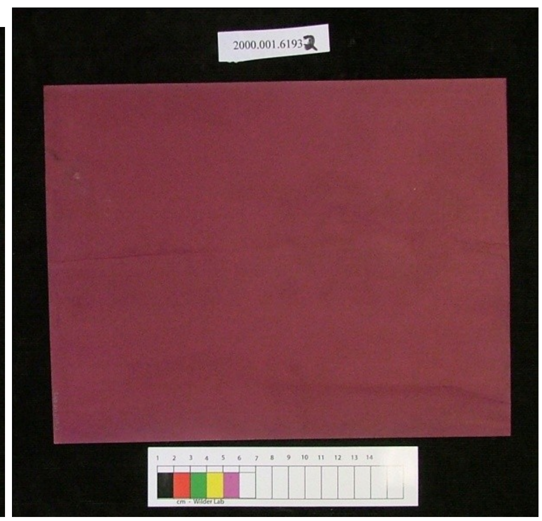
	Before	During	After
Color photo	x		x

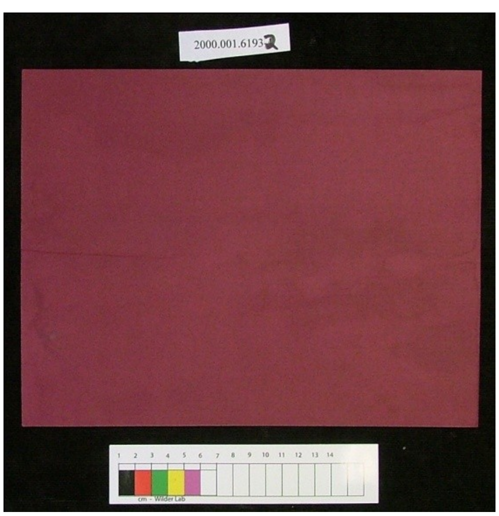
Additional Comments:


Finished
2000.001.6193-2


2000.001.6193


2000.001.6193


2000.001.6193


2000.001.6193


2000.001.6193
Christopher Lee Heard
Houston

Artifact 2000.001.6193-3

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-3 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Christopher..."
2 maroon card stock
mold
wrinkles
In Acetate

Proposed Treatment:
wash
flatten

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

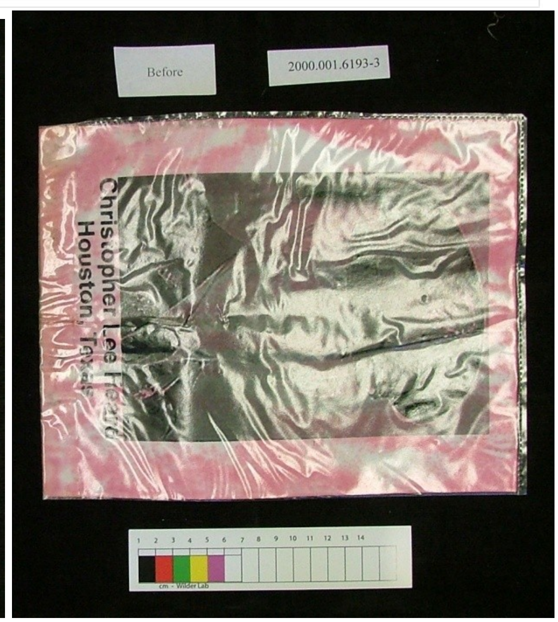
Testing:
ink
Light

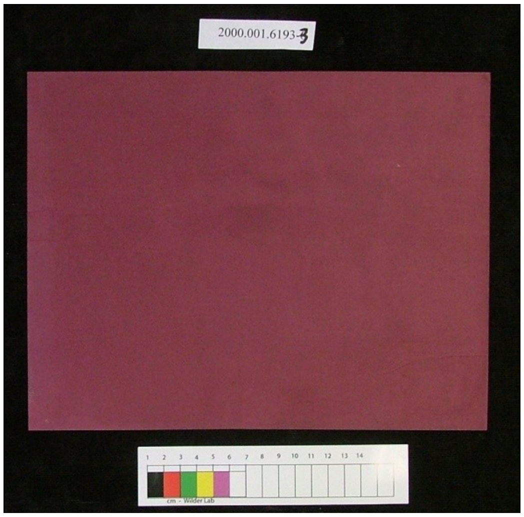
Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles. It was decided that MTMS/Si was not necessary for its conservation

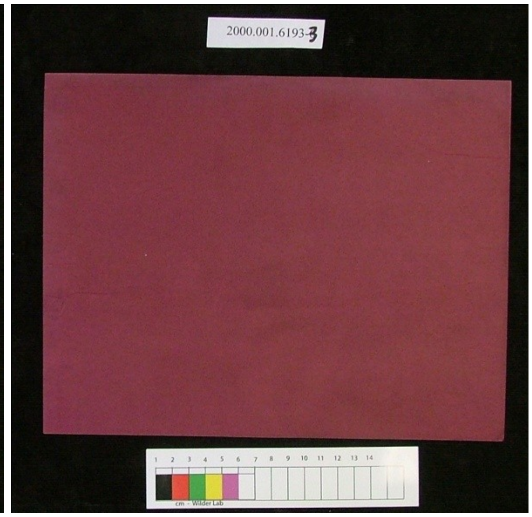
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.6193-3


2000.001.6193-3


2000.001.6193-3


2000.001.6193-3
Christopher Lee Heard
Houston, Texas


Finished
2000.001.6193-3
Christopher Lee Heard
Houston, Texas


Finished
2000.001.6193-3

Artifact 2000.0016193-4

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/5/05 **Artifact No.** 2000.001.6193-4 **Initials** ebe

Description and Condition:
Maroon card stock
wrinkled
8.5x11 white paper
printer ink
in acetate
tears
wrinkled

Proposed Treatment:
wash
flatten
mend
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

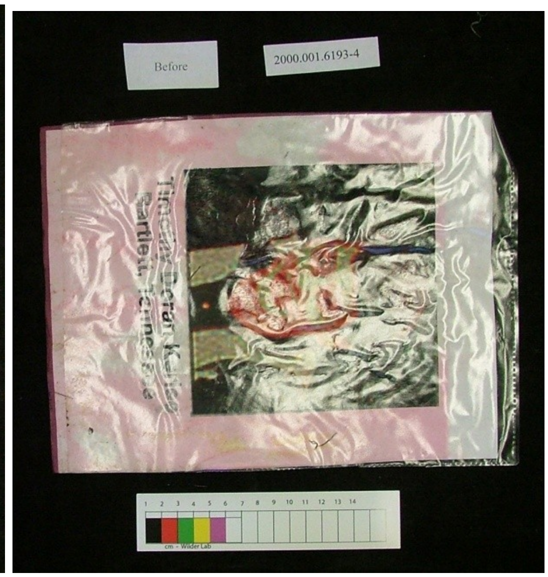
Testing:
ink- h2osafe
lights -nothing

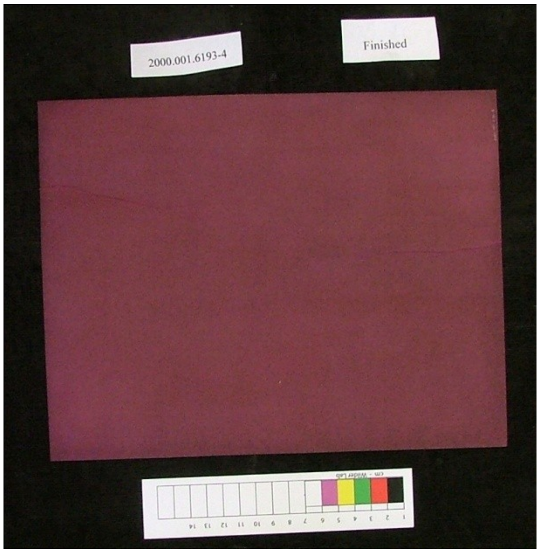
Conclusions:
good to get out of the acetate
looks beter with mends and flattening
much stronger

Graphic Record

	Before	During	After
Color photo	x		x

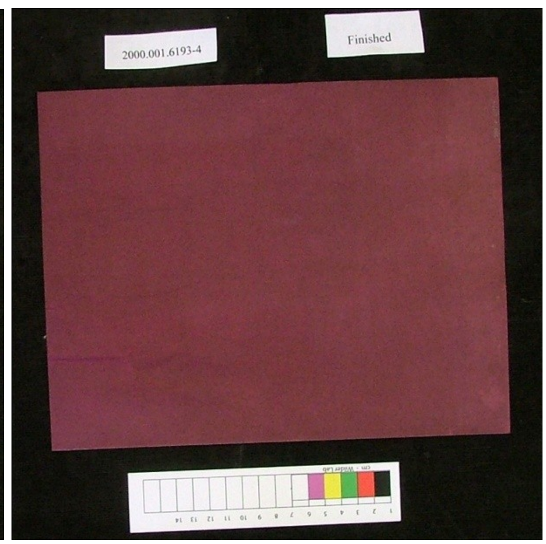
Additional Comments:




2000.001.6193-4
Finished


2000.001.6193-4
Finished


2000.001.6193-4
Finished
Timothy Doran Kerlee
Bartlett, Tennessee


2000.001.6193-4
Finished

Artifact 2000.001.6193-5

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-10 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Miranda Adams"
2 maroon card stock
mold
wrinkles
In acetate

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

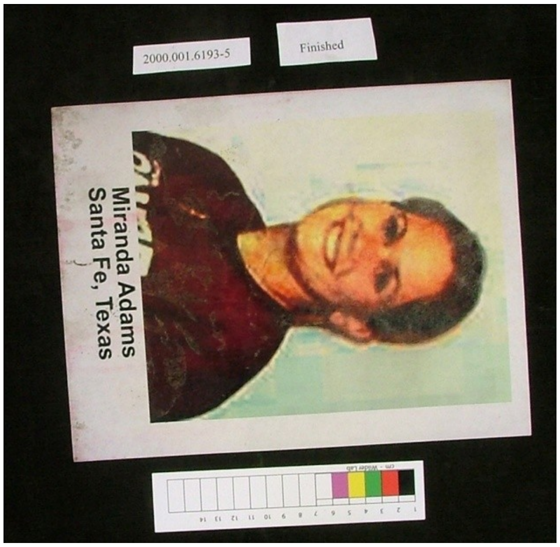
Testing:
ink
Light

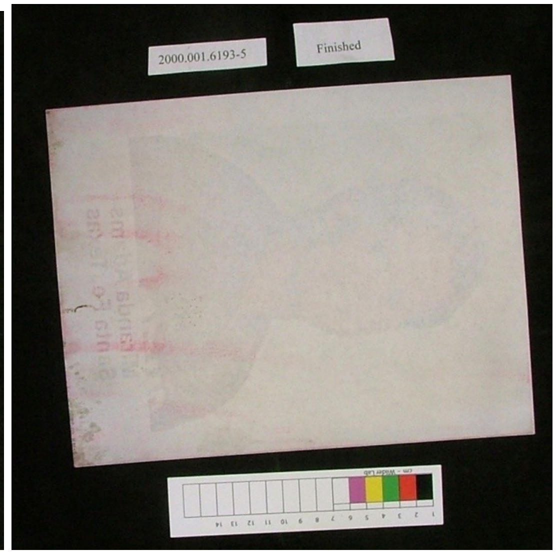
Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles

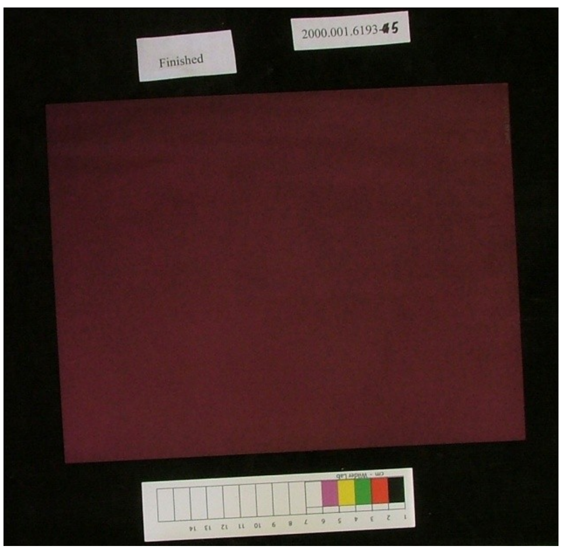
Graphic Record

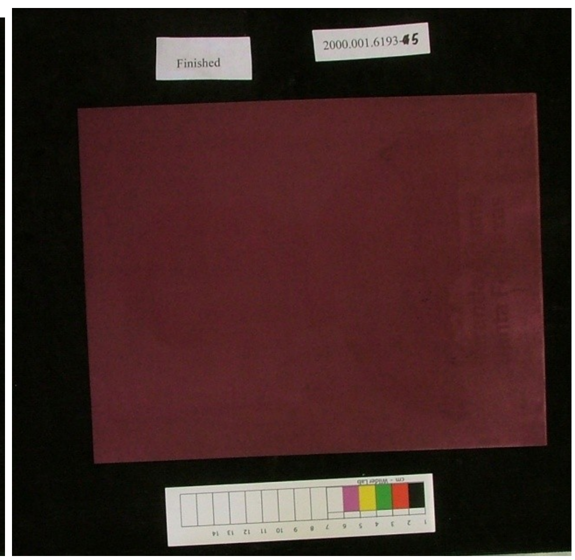
	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6193-5
Finished
Miranda Adams
Santa Fe, Texas


2000.001.6193-5
Finished


Finished
2000.001.6193-5


Finished
2000.001.6193-5

Artifact 2000.0016193-6

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-10 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Jamie Lynn Hand"
maroon card stock
mold
wrinkles
In acetate

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

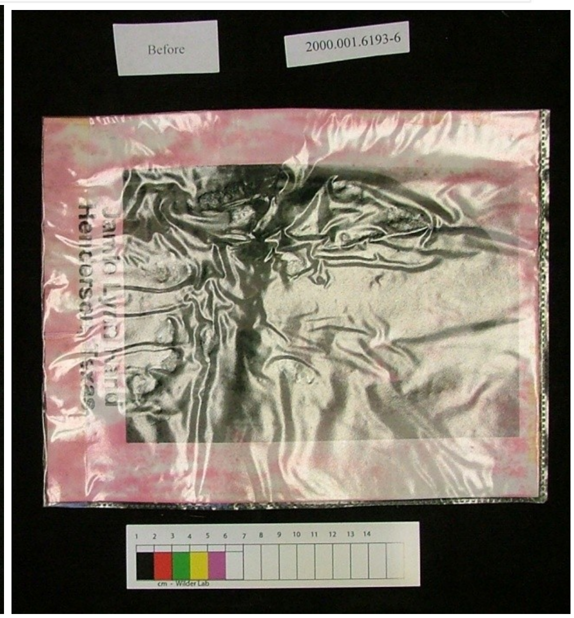
Testing:
ink
Light

Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles

Graphic Record

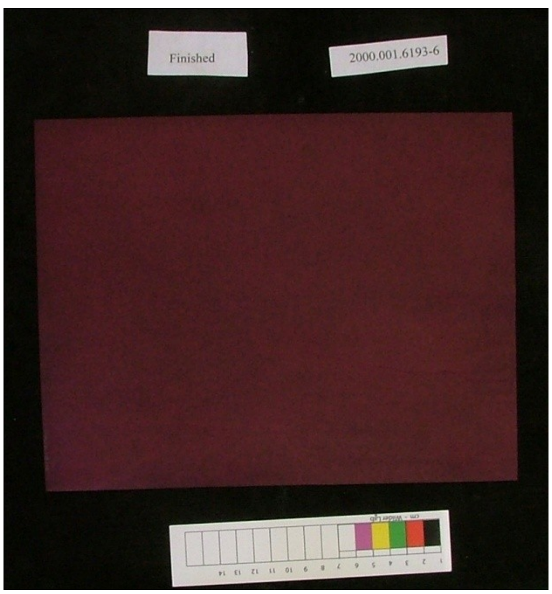
	Before	During	After
Color photo	x		x

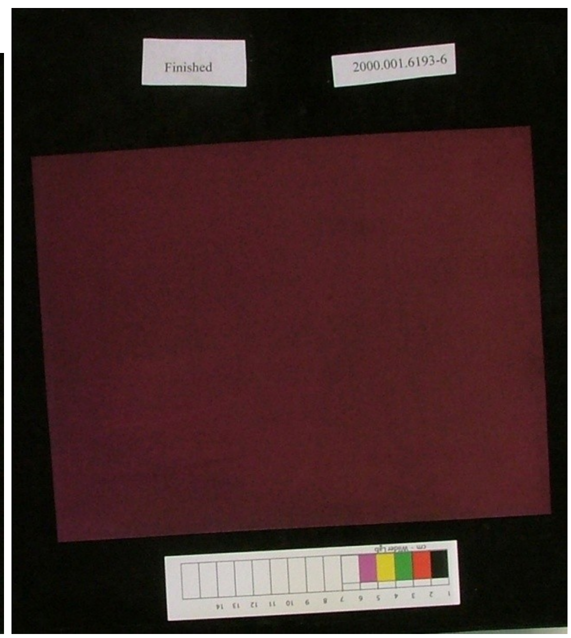
Additional Comments:




Finished
2000.001.6193-6
Jamie Lynn Hand
Henderson, Texas


Finished
2000.001.6193-6


Finished
2000.001.6193-6


Finished
2000.001.6193-6

Artifact 2000.001.6193-7

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-7 **Initials** ebe

Description and Condition:
1 page maroon card stock
1 8.5x11 white paper with computer printed image
in acetate
wrinkled
maroon bleed from card stock

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

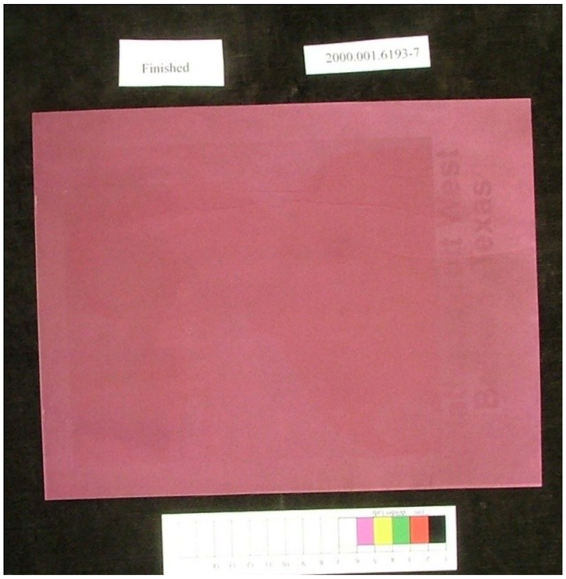
Testing:
ink-safe
lights-nothing

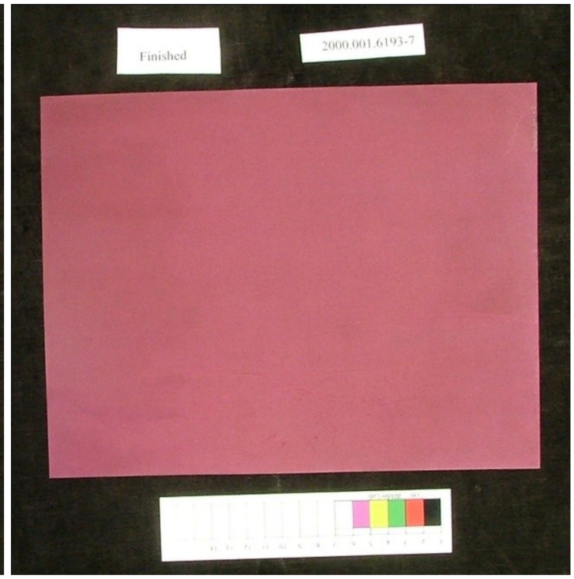
Conclusions:
In good shape to begin with, now only looks better
good to be out of the acetate

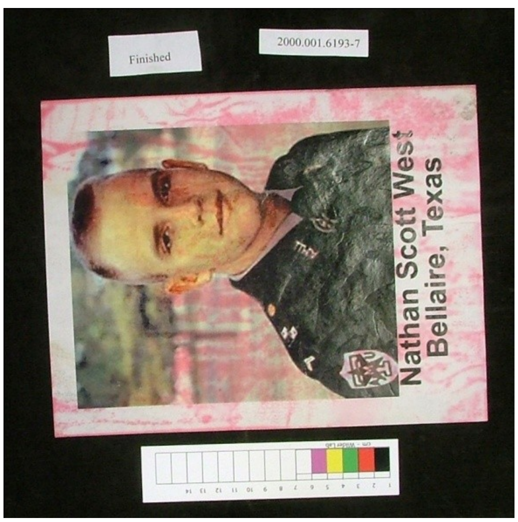
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments: The after photos had faults in the program, so they are not present


Finished
2000.001.6193-7


Finished
2000.001.6193-7


Finished
2000.001.6193-7
Nathan Scott West
Bellaire, Texas


Finished
2000.001.6193-7

Artifact 2000.001.6193-8

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-8 **Initials** ebe

Description and Condition:
2 page maroon card stock
1 8.5x11 white paper with computer printed image
in acetate
wrinkled
maroon bleed from card stock
"Jamie Lynn Hand"

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

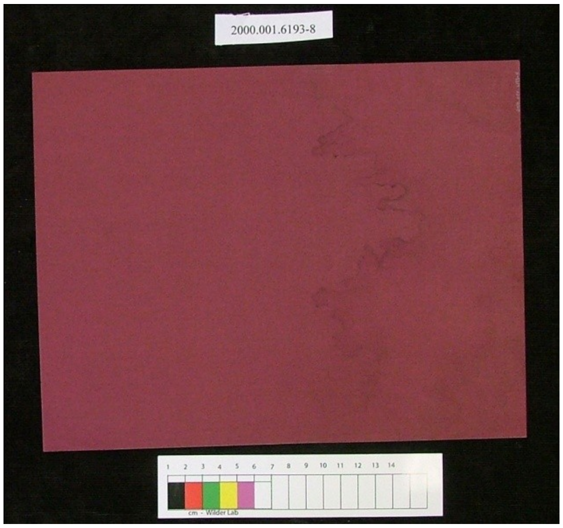
Testing:
ink-safe
lights-nothing

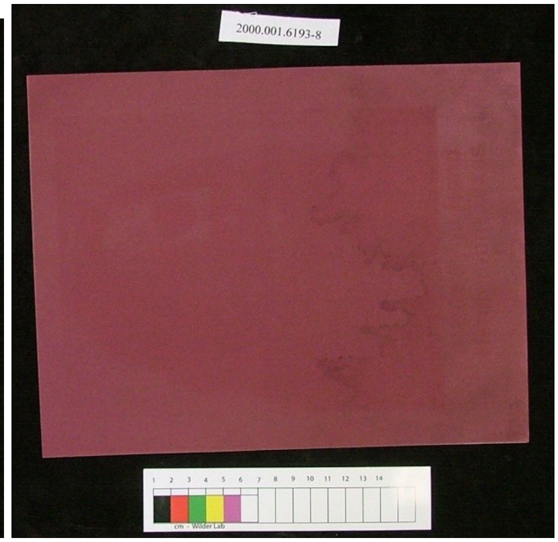
Conclusions:
In good shape to begin with, now only looks better
good to be out of the acetate

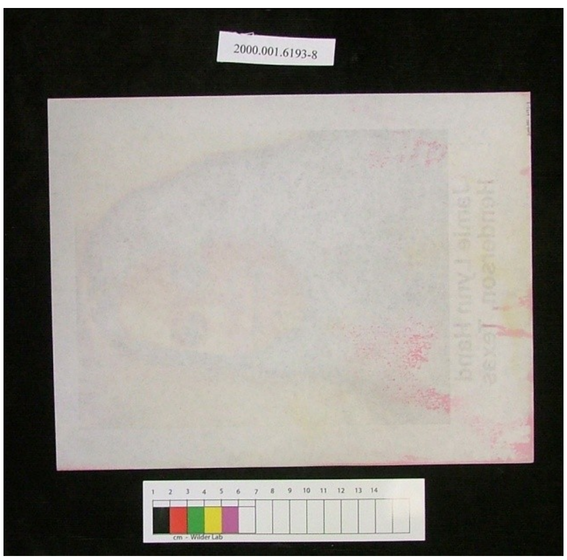
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6193-8
cm - Wilder Lab


2000.001.6193-8
cm - Wilder Lab


2000.001.6193-8
cm - Wilder Lab


2000.001.6193-8
Jamie Lynn Hand
Henderson, Texas
cm - Wilder Lab

Artifact 2000.001.6193-9

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-9 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Jerry Self"
1 maroon card stock
mold
wrinkles
In acetate

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
Light

Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles

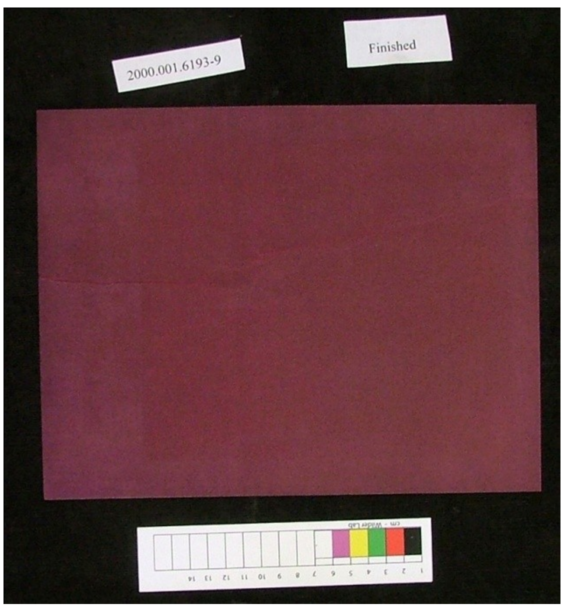
Graphic Record

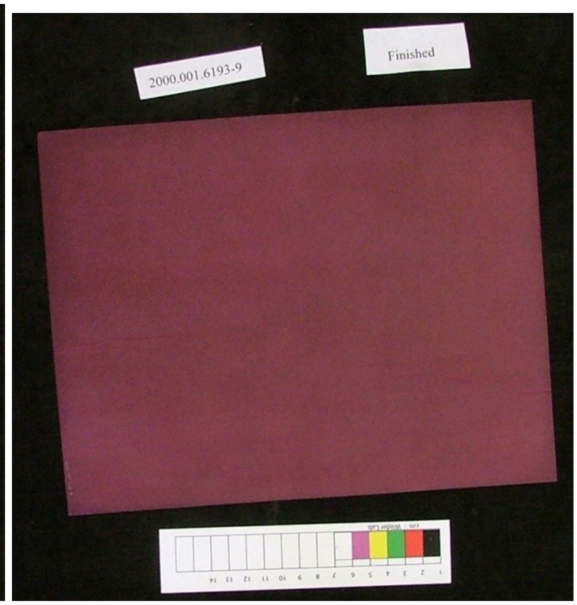
	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6193-9
Finished


2000.001.6193-9
Finished
Jerry Self
Arlington, Texas


2000.001.6193-9
Finished


2000.001.6193-9
Finished

Artifact 2000.001.6193-10

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-10 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink picture"Christopher Breen"
maroon card stock
mold
wrinkles
In acetate

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
Light

Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles

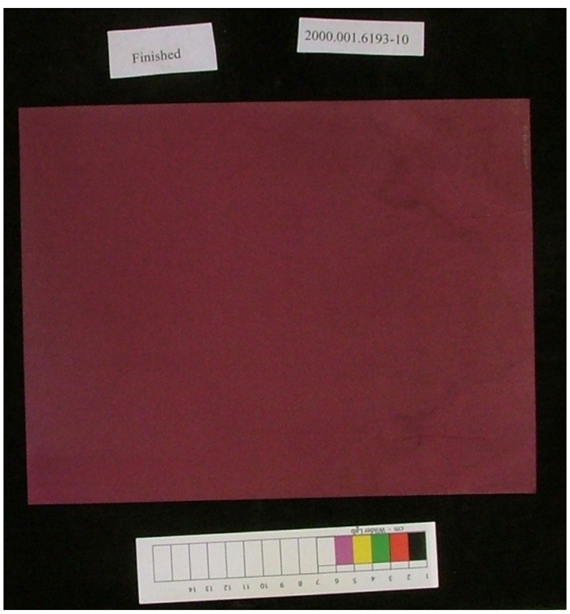
Graphic Record

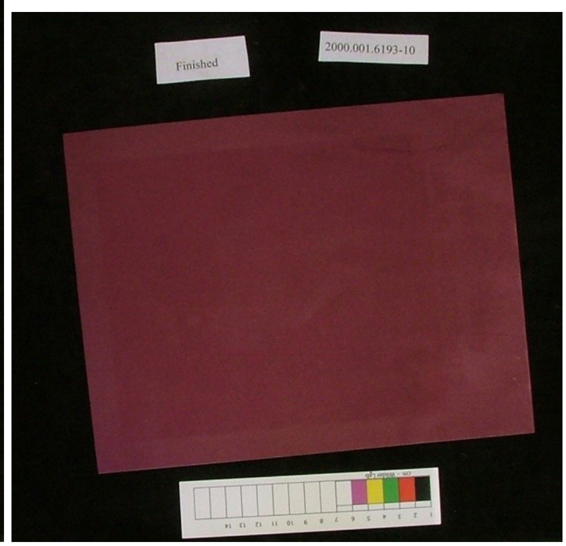
	Before	During	After
Color photo	x		x

Additional Comments:


Finished
2000.001.6193-10
Christopher Breen
Austin, Texas


Finished
2000.001.6193-10


Finished
2000.001.6193-10


Finished
2000.001.6193-10

Artifact 2000.001.6193-12

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6193-12 **Initials** ebe

Description and Condition:
White 8.5x11 with printer ink
maroon card stock
mold
wrinkles

Proposed Treatment:
wash
flatten
MTMS/Si

Results: [X] Excellent [X] Good [ ] Fair [ ] Poor

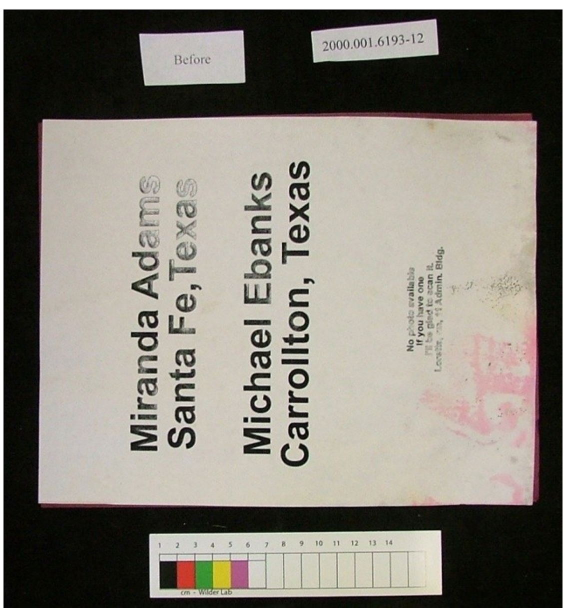
Testing:
ink
Light

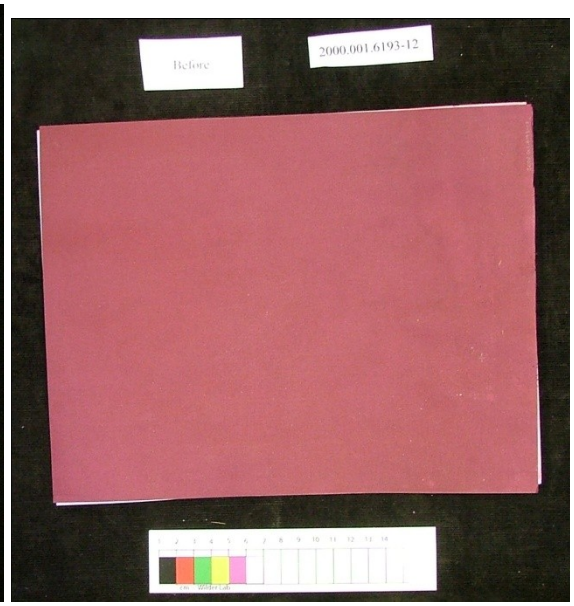
Conclusions:
looks as good as can get. Flat and strong. Card stock still retains memory of wrinkles, the photo of the card stock does not seem to be true to color and it looks alot better, but this has already been curated before it was discovered. Also there do not seem to be any before photos

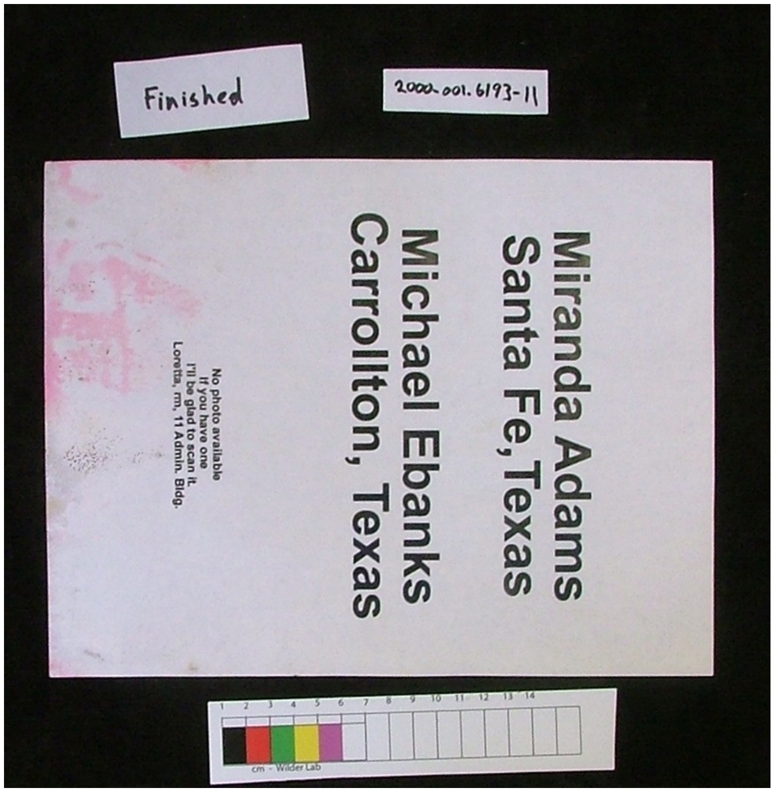
Graphic Record

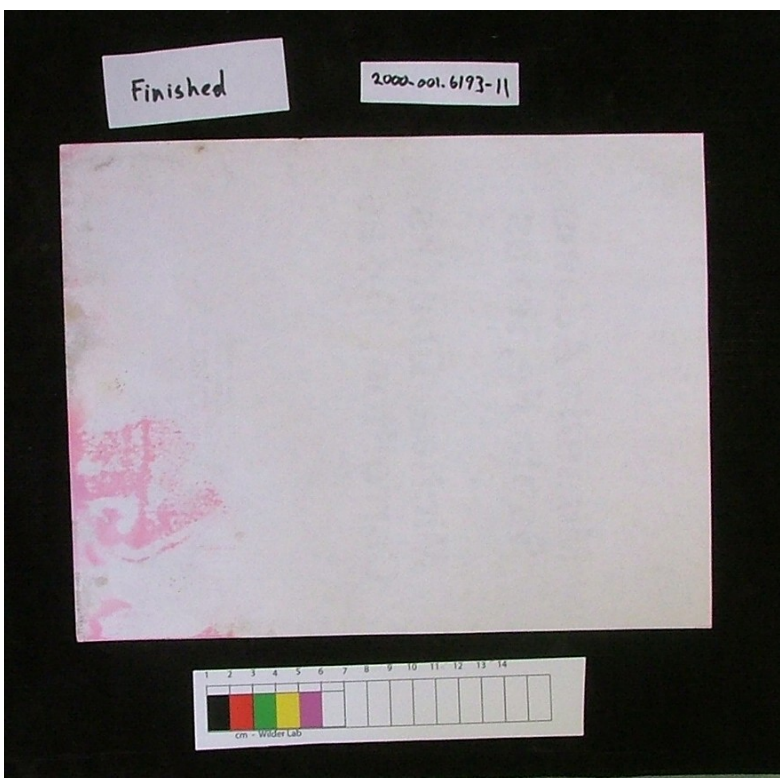
	Before	During	After
Color photo	x		x

Additional Comments:






Finished
2000-001.6193-11
Miranda Adams
Santa Fe, Texas
Michael Ebanks
Carrollton, Texas
No photo available
If you have one
I'll be glad to scan it.
Loretta, rm. 11 Admin. Bldg.
cm - Wilder Lab


Finished
2000-001.6193-11
cm - Wilder Lab

Artifact 2000.001.6195

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/19/05 **Artifact No.** 2000.001.6195 **Initials** ebe

Description and Condition:
2 parts, once pasted together
1. Crayon on white bulk paper-8.5x11
"In remembrance of Chad Anthony Powell"
2. Mounted on construction paper, possibly purple

Lots of surface dirt
candle wax and possibly a candle having been placed on the paper

Proposed Treatment:
Brush to remove the majority of the surface dirt and mold
Wash
Flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
Ink-fine
lights-nothing

Conclusions:
They are both in much better shape since washing
After MTMS treatment, it is noticbly stronger

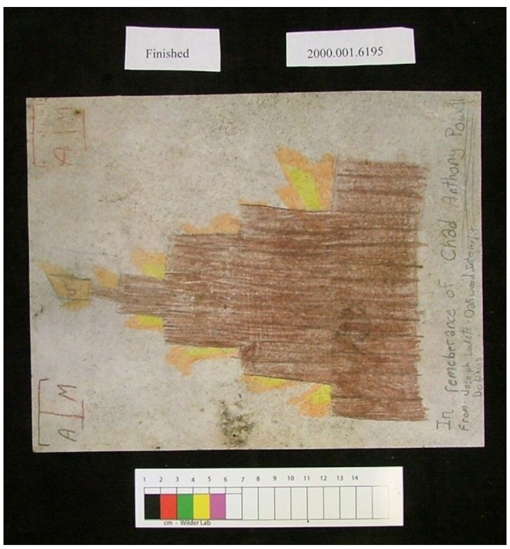
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6195
Before


2000.001.6195
Before


Finished
2000.001.6195


Finished
2000.001.6195


Finished
2000.001.6195


Finished
2000.001.6195

Artifact 2000.001.6197

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6197 **Initials** ebe

Description and Condition:
8.5x11 white paper
xerox on one side
blue marker ink on other
voids and tears
lots of surface dirt
mold
vegetation

Proposed Treatment:
mechanically clean
wash
flatten
mend and fill
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

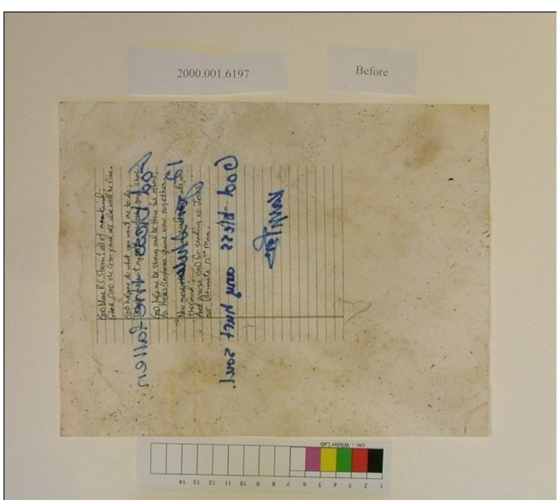
Testing:
ink
lights

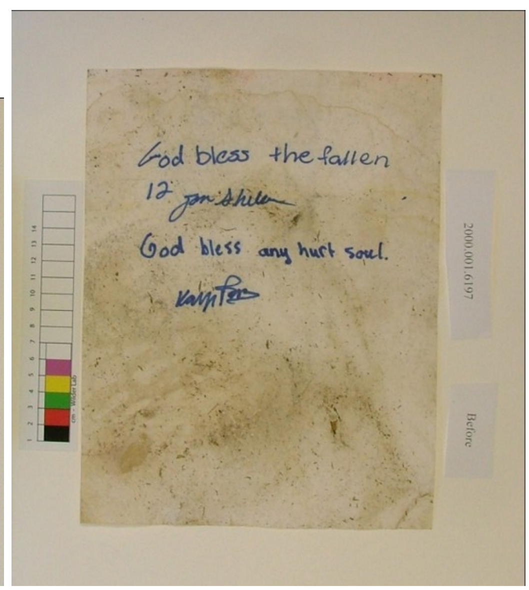
Conclusions:
looks great and feels great

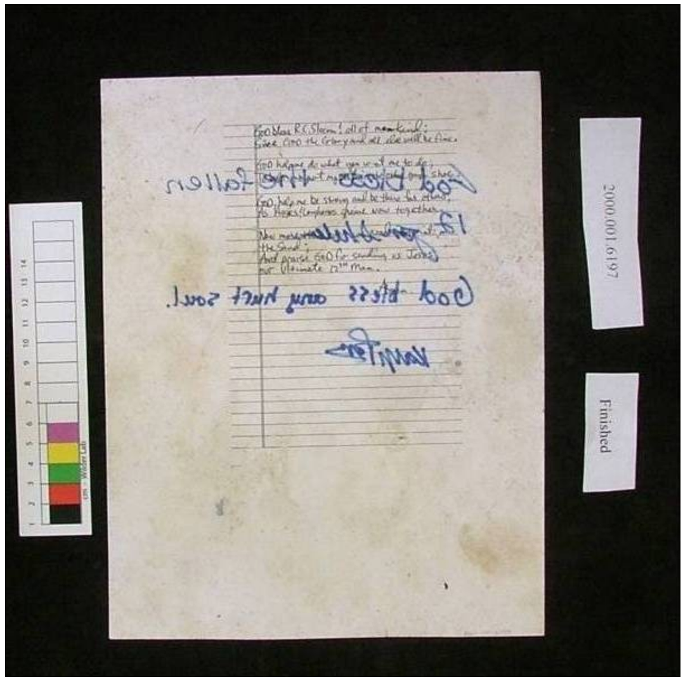
Graphic Record

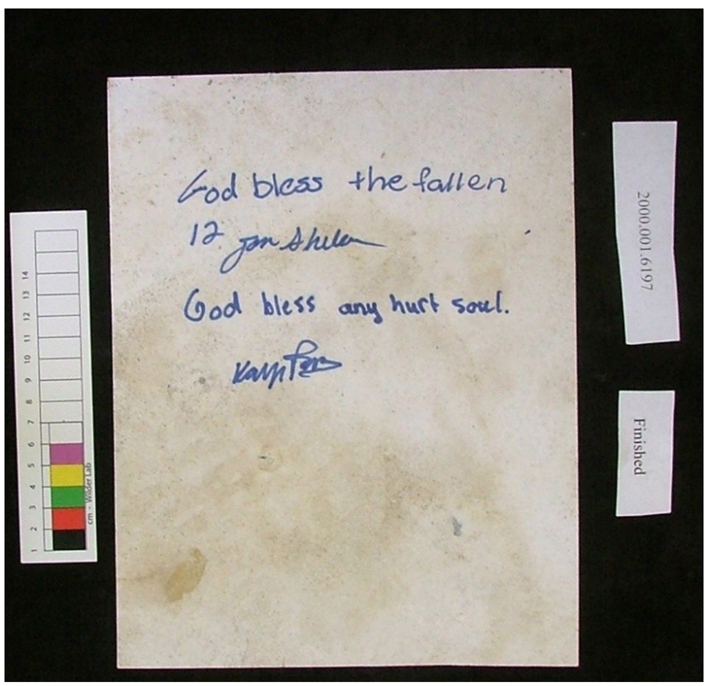
	Before	During	After
Color photo	x		x

Additional Comments:






2000.001.6197
Finished


God bless the fallen
God bless any hurt soul.
2000.001.6197
Finished

Artifact 2000.001.6198

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6198 **Initials** ebe

Description and Condition:
8.5x11 white paper
Xerox ink message "November 19th..."
candle wax stains
holes
void along top
surface dirt
mold

Proposed Treatment:
mechanically clean
wash
flatten
fill
MTMS/si

Retreat

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink-non soluble
light-shows candle wax

Conclusions:
The document looked good after flattening and washing. It did not look so good after treatment since the solution had too much Si oil in it, and it gave it a translucent quality.

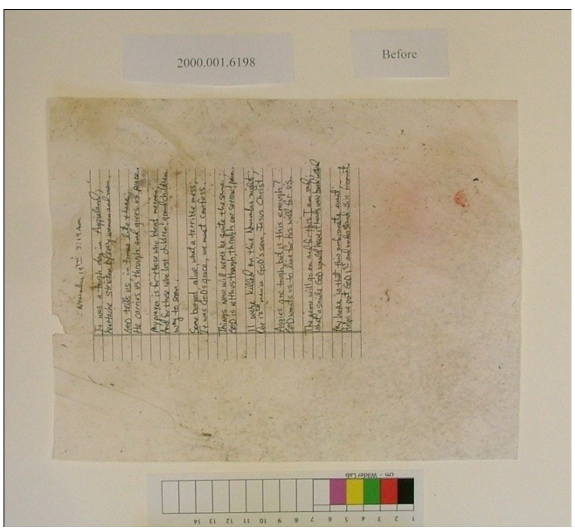
After treatment, it looked better, but it seems to have accented the creases or repulping that occurred in the upper left corner. It feels flat, but it does not look it

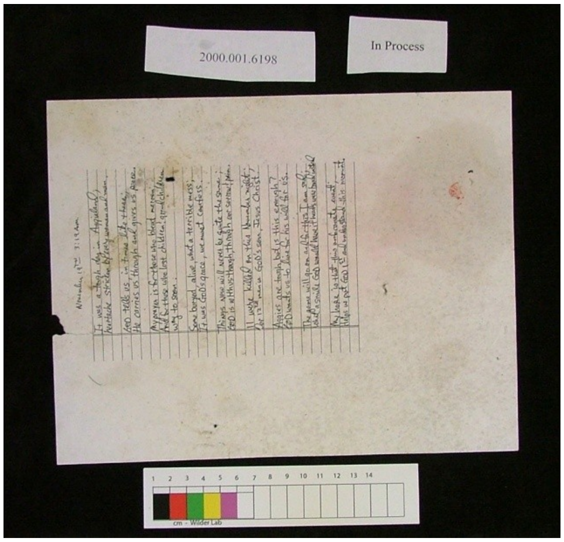
After retreatment, it looks alot better

Graphic Record

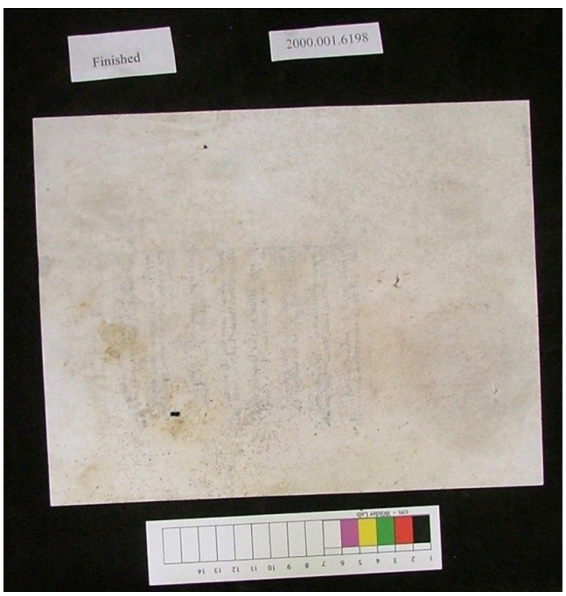
	Before	During	After
Color photo	x	x	x

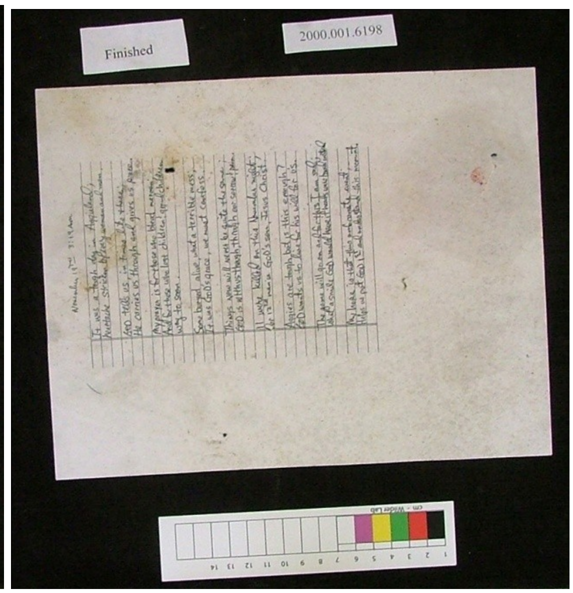
Additional Comments:




2000.001.6198
In Process
cm - Wilder Lab


2000.001.6198
In Process
cm - Wilder Lab


Finished
2000.001.6198


Finished
2000.001.6198

Artifact 2000.001.6199

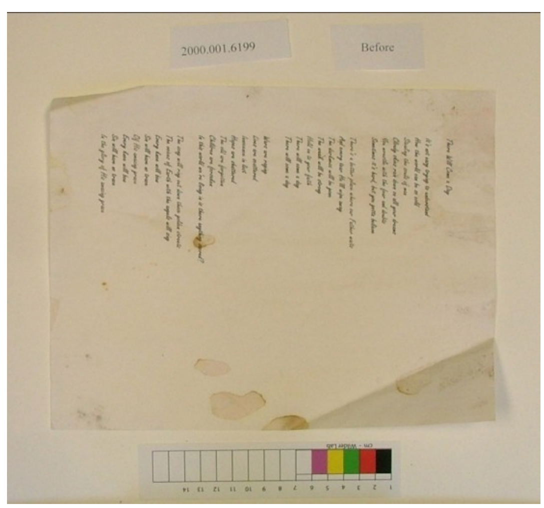
Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date	10/13/05
Artifact No.	2000.001.6199
Initials	ebe
Description and Condition:	white 8.5 x 11copy paper printer ink candle wax staining mold creases yellowing
Proposed Treatment:	wash flatten MTMS/si treatment
Results:	☒ Excellent ☐ Good ☐ Fair ☐ Poor
Testing:	Ink is not h2o soluble light showed nothing
Conclusions:	looks much better as the fold and the yellowing is gone. the candle was is diminished

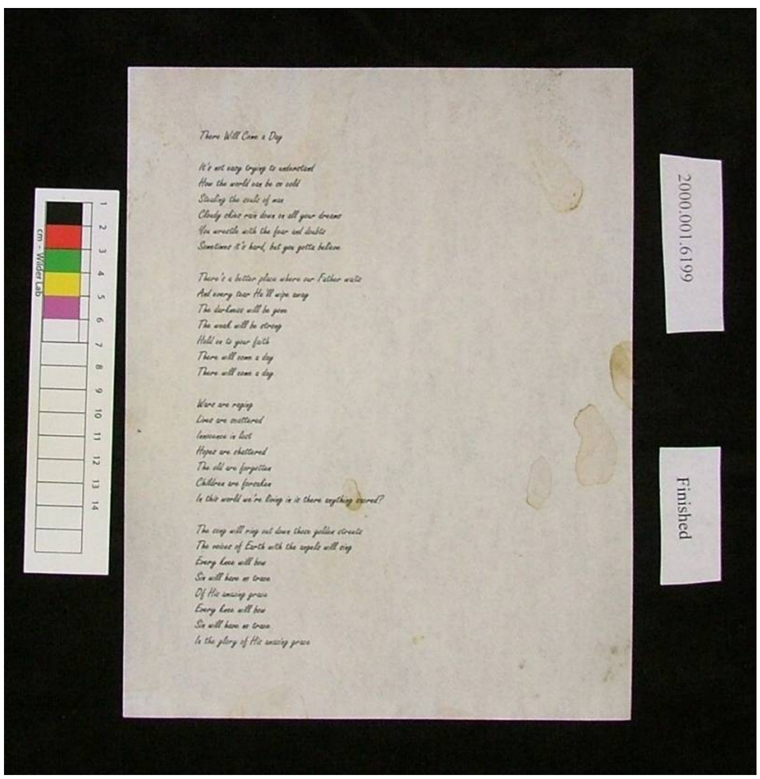
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:	




2000.001.6199
Finished
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm – Wilder Lab


There Will Come a Day
It's not easy trying to understand
How the world can be so cold
Stealing the souls of men
Cloudy skies rain down on all your dreams
You wrestle with the fear and doubts
Sometimes it's hard, but you gotta believe
There's a better place where our Father waits
And every tear He'll wipe away
The darkness will be gone
The weak will be strong
Hold on to your faith
There will come a day
There will come a day
Wars are raging
Lives are scattered
Innocence is lost
Hopes are shattered
The old are forgotten
Children are forsaken
In this world we're living in is there anything sacred?
The song will ring out down those golden streets
The voices of Earth with the angels will sing
Every knee will bow
Sin will have no trace
Of His amazing grace
Every knee will bow
Sin will have no trace
In the glory of His amazing grace
2000.001.6199
Finished
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm – Wilder Lab

Artifact 2000.001.6201

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6201 **Initials** ebe

Description and Condition:
"bonfire poem on 6.5x8 inch pink paper held in maroon mat with tape.
computer print

Proposed Treatment:
remove mat and tape
mechanically clean
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

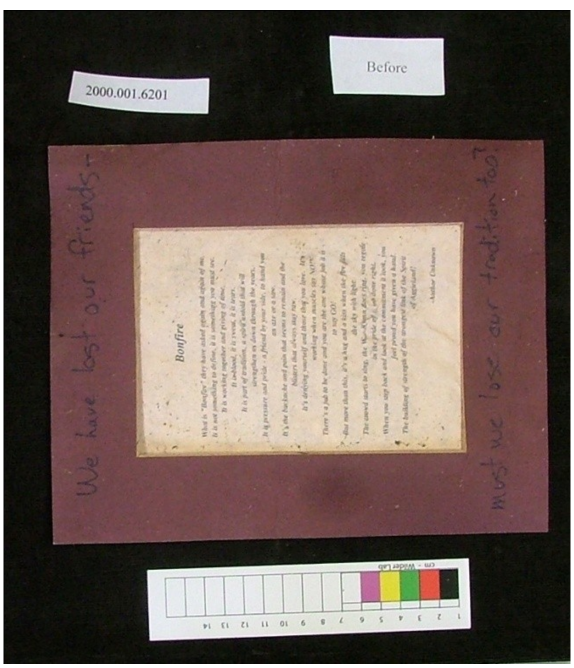
Testing:
ink
light

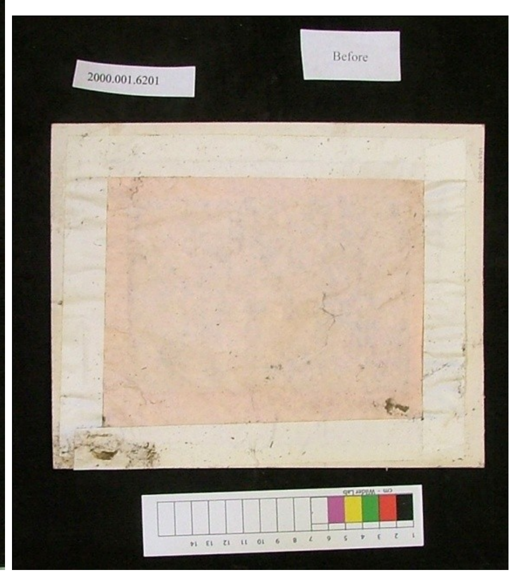
Conclusions:
It will be much more stable away form the mat and tape. An attempt was made to remove all of the adhesive, but some may remain behind. If this yellows with age, another attempt to remove it will be necessary, but the MTMS treatment should keep it from degrading as a result of the adhesive

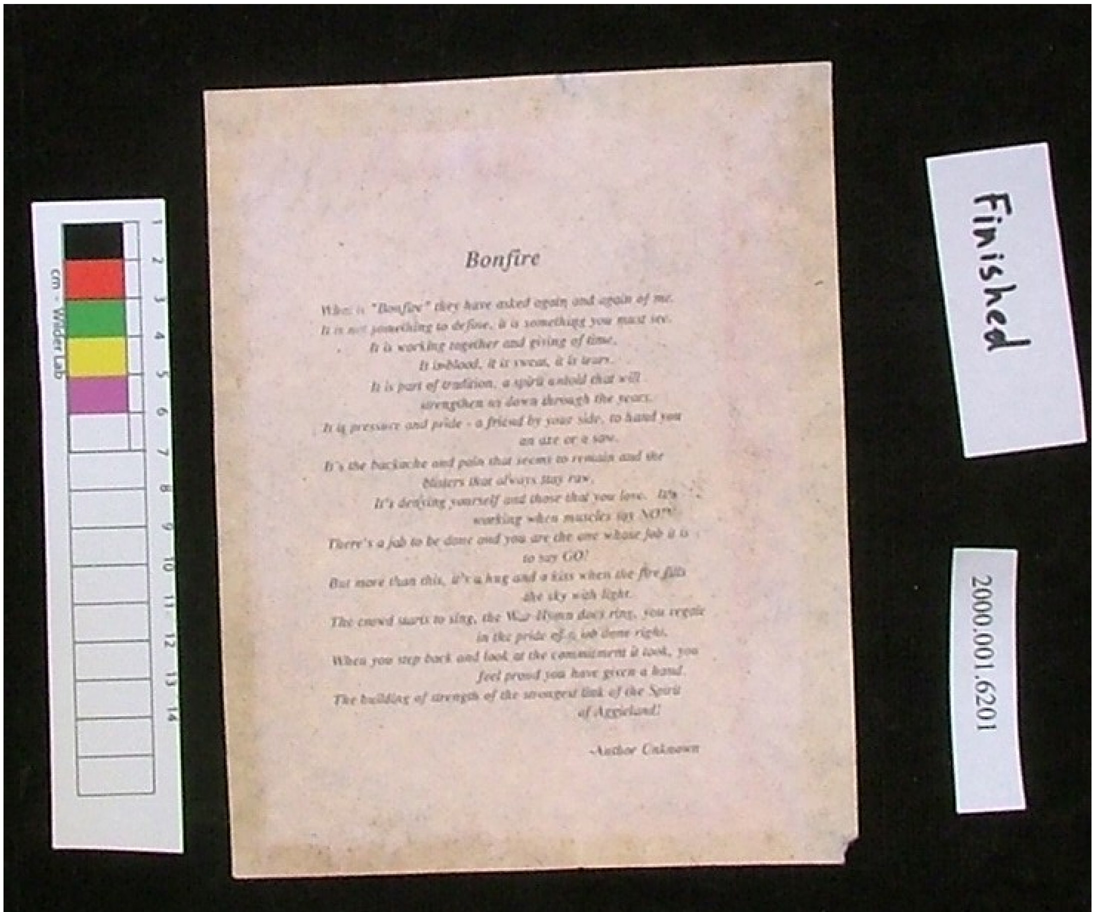
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:



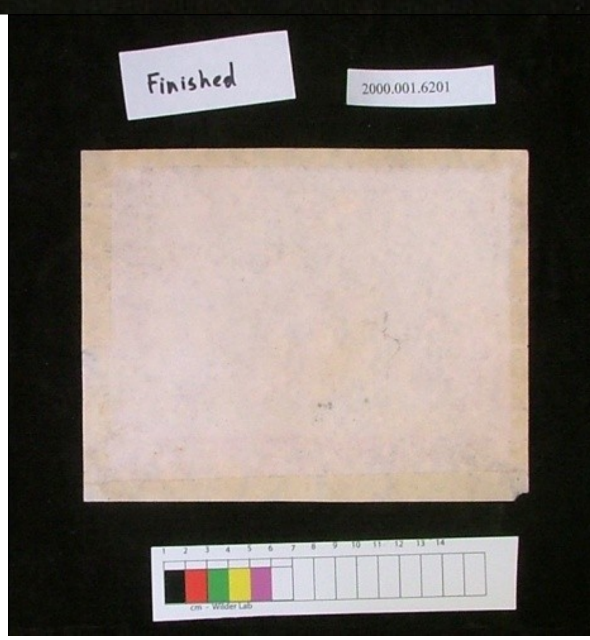




Bonfire

What is "Bonfire" they have asked again and again of me.
It is not something to define, it is something you must see.
It is working together and giving of time.
It is blood, it is sweat, it is tears.
It is part of tradition, a spirit untold that will
strengthen us down through the years.
It is pressure and pride - a friend by your side, to hand you
an axe or a saw.
It's the backache and pain that seems to remain and the
blisters that always stay raw.
It's denying yourself and those that you love. It's
working when muscles say NO!"
There's a job to be done and you are the one whose job it is
to say GO!
But more than this, it's a hug and a kiss when the fire fills
the sky with light.
The crowd starts to sing, the War Hymn does ring, you regale
in the pride of a job done right.
When you step back and look at the commitment it took, you
feel proud you have given a hand.
The building of strength of the strongest link of the Spirit
of Aggieland!

-Author Unknown



Artifact 2000.001.6202

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/13/05 **Artifact No.** 2000.0001.6202 **Initials** ebe

Description and Condition:
White 8.5x11 white paper
media-printer ink ink
surface dirt
water stains
"The Stars" poem to Jamie
Stains from candle wax

Proposed Treatment:
Wash
Flatten
MTMS/Si treatment

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

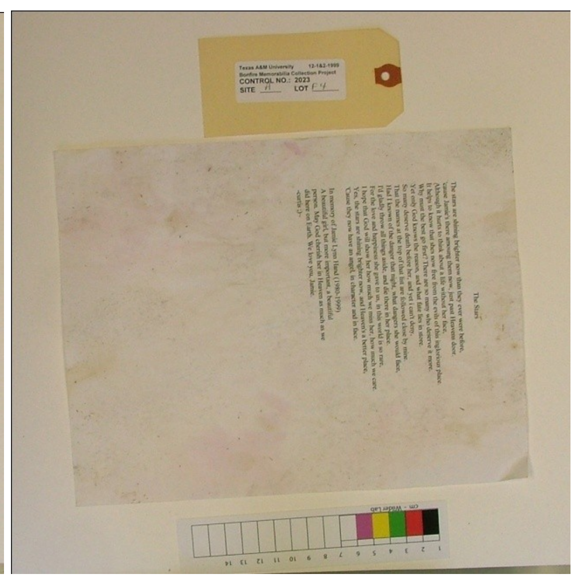
Testing:
Ink
Lights

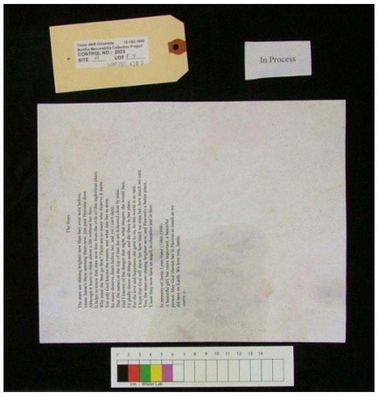
Conclusions:
looks great and very durable
dirt came out but the candle wax remains

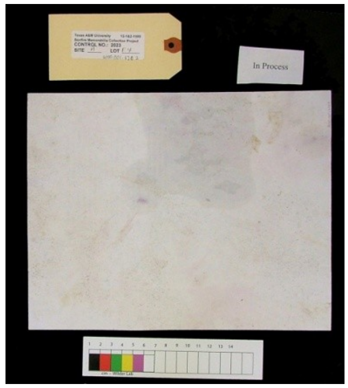
Graphic Record

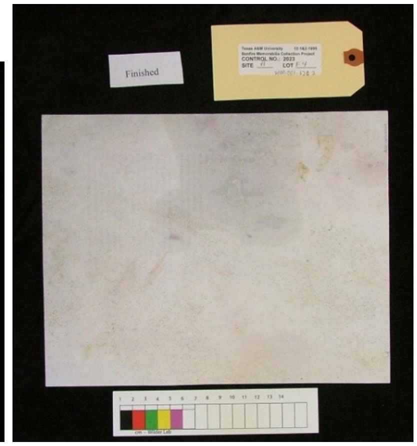
	Before	During	After
Color photo	x	x	x

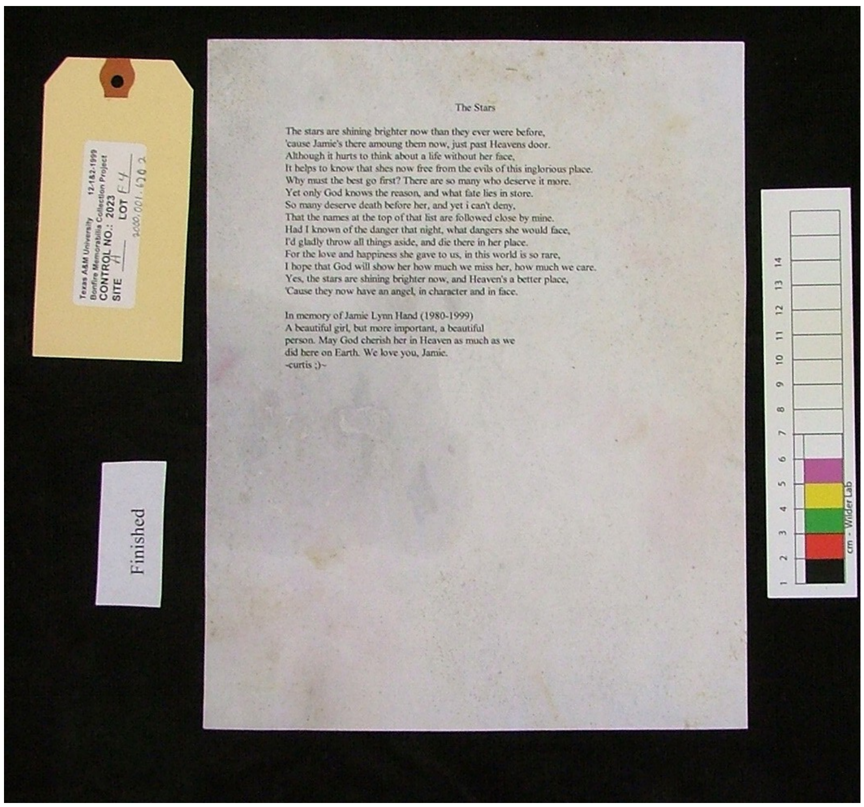
Additional Comments:




In Process


In Process


Finished


Texas A&M University 12-182-1999
Bonfire Memorabilia Collection Project
CONTROL NO.: 2023
SITE A LOT E-4
Finished
The Stars
The stars are shining brighter now than they ever were before,
'cause Jamie's there amoung them now, just past Heavens door.
Although it hurts to think about a life without her face,
It helps to know that shes now free from the evils of this inglorious place.
Why must the best go first? There are so many who deserve it more.
Yet only God knows the reason, and what fate lies in store.
So many deserve death before her, and yet i can't deny,
That the names at the top of that list are followed close by mine.
Had I known of the danger that night, what dangers she would face,
I'd gladly throw all things aside, and die there in her place.
For the love and happiness she gave to us, in this world is so rare,
I hope that God will show her how much we miss her, how much we care.
Yes, the stars are shining brighter now, and Heaven's a better place,
'Cause they now have an angel, in character and in face.
In memory of Jamie Lynn Hand (1980-1999)
A beautiful girl, but more important, a beautiful
person. May God cherish her in Heaven as much as we
did here on Earth. We love you, Jamie.
~curtis ;)~
cm - Wilder Lab

Artifact 2000.001.6203

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/18/05 **Artifact No.** 2000.001.6203 **Initials** ebe

Description and Condition:
Ivory envelop
surface dirt
mold

Proposed Treatment:
brush
wash
flatten
MTMS/si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
Ink-none
light-nothing disinct

Conclusions:
Much cleaner and stronger

Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:


2000.001.6203
In Process
cm - Wilder Lab


2000.001.6203
In Process
cm - Wilder Lab


2000.001.6203
Finished
cm - Wilder Lab


2000.001.6203
Finished
cm - Wilder Lab

Artifact 2000.001.6204-1

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/8/05 **Artifact No.** 2000.001.6204-1 **Initials** ebe

Description and Condition:
Green marker on thick paper
14x12 approx.

Proposed Treatment:
Mechanically clean
Wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☒ Fair ☐ Poor

Testing:
Lights
ink

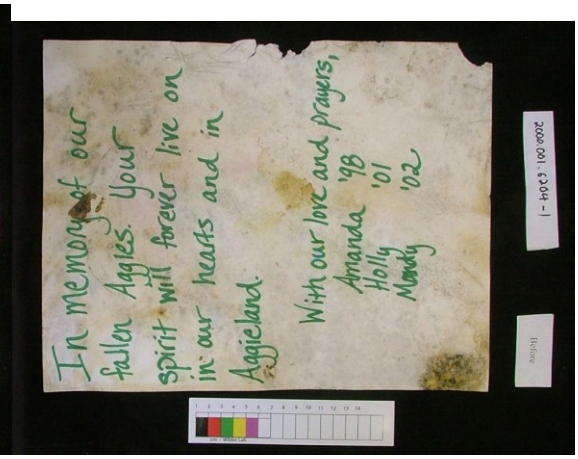
-but not MTMS

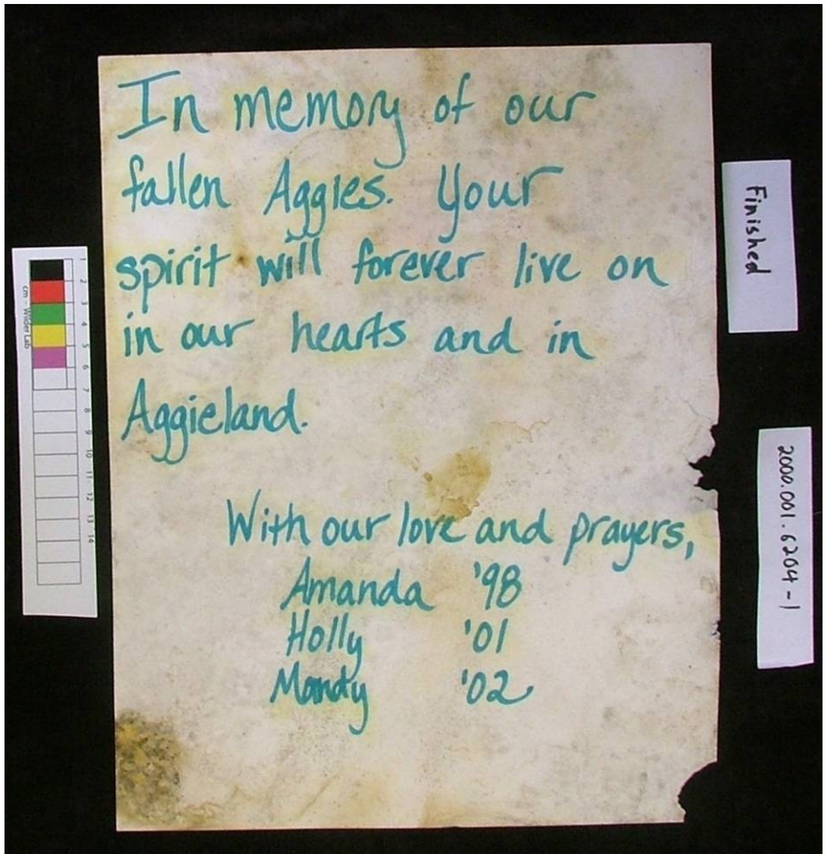
Conclusions:
After washing and flattening it looked great. A lot cleaner and better. After putting it into the MTMS/Si solution the yellow in the green seemed to become activated and bled. As a result there is a ghosting of yellow aroung all of the letters front and back. This is now more stable, it does look better.

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




In memory of our
fallen Aggies. Your
spirit will forever live on
in our hearts and in
Aggieland.
With our love and prayers,
Amanda '98
Holly '01
Mandy '02
Finished
2000.001.6204-1


Finished
2000.001.6204-1

Artifact 2000.001.6204

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6204 **Initials** ebe

Description and Condition:
Post card with writing and stamp
bonfire image in heat setting ink
surface dirt
mold
stains

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

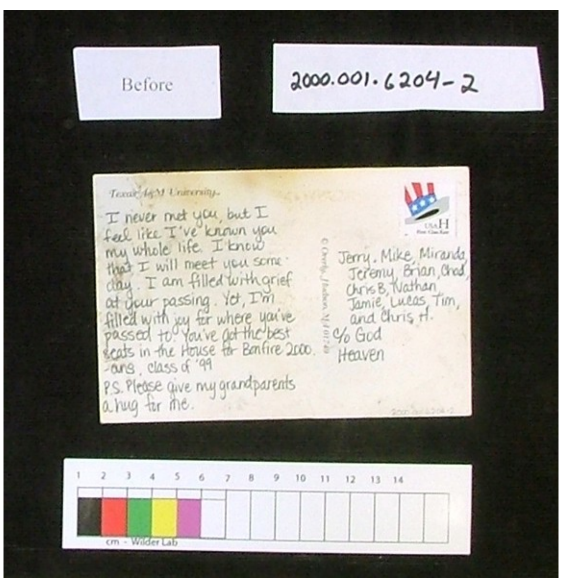
Testing:
ink
lights

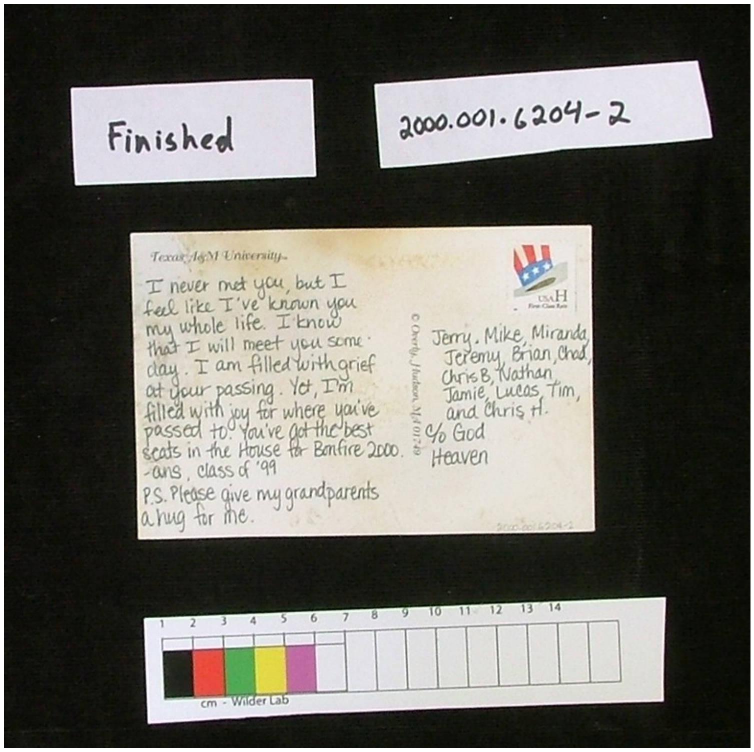
Conclusions:
It started of well and looks even better after completion

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




Finished
2000.001.6204-2
Texas A&M University
I never met you, but I feel like I've known you my whole life. I know that I will meet you some-day. I am filled with grief at your passing. Yet, I'm filled with joy for where you've passed to. You've got the best seats in the House for Bonfire 2000.
-ans, class of '99
P.S. Please give my grandparents a hug for me.
Jerry, Mike, Miranda, Jeremy, Brian, Chad, Chris B, Nathan, Jamie, Lucas, Tim, and Chris H.
c/o God
Heaven
USA H
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab


Finished
2000.001.6204-2
TEXAS A&M
UNIVERSITY
Bonfire
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab

Artifact 2000.001.6206d

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.6206d **Initials** ebe

Description and Condition:
8.5x11 white paper with computer or xerox print
in acetate
creased
stained
mold
surface dirt

Proposed Treatment:
remove from acetate
wash
flatten
MTMS/si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

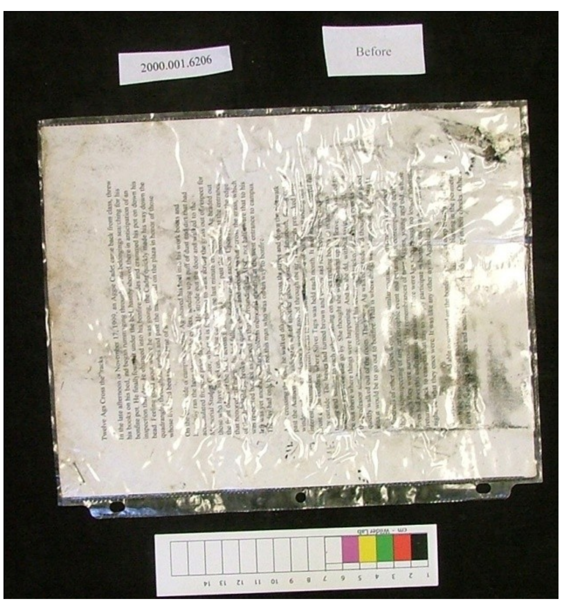
Testing:
ink
light

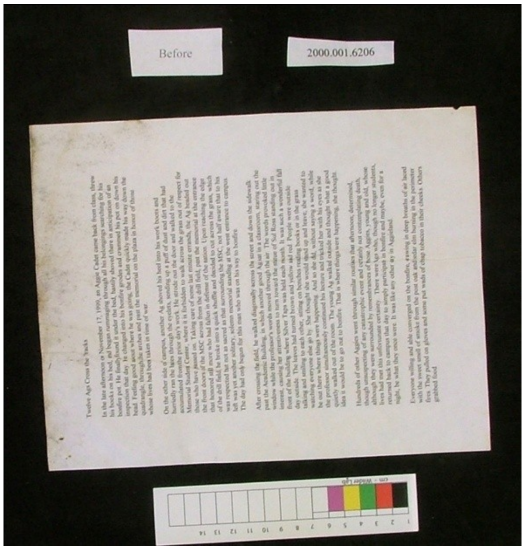
Conclusions:
Frankly, it looks about the same, but it was good to get it out of the acetate and to treat it.

Graphic Record

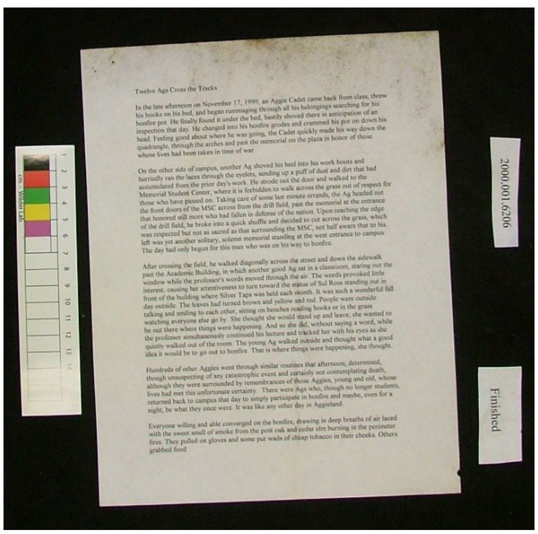
	Before	During	After
Color photo	x		x

Additional Comments:



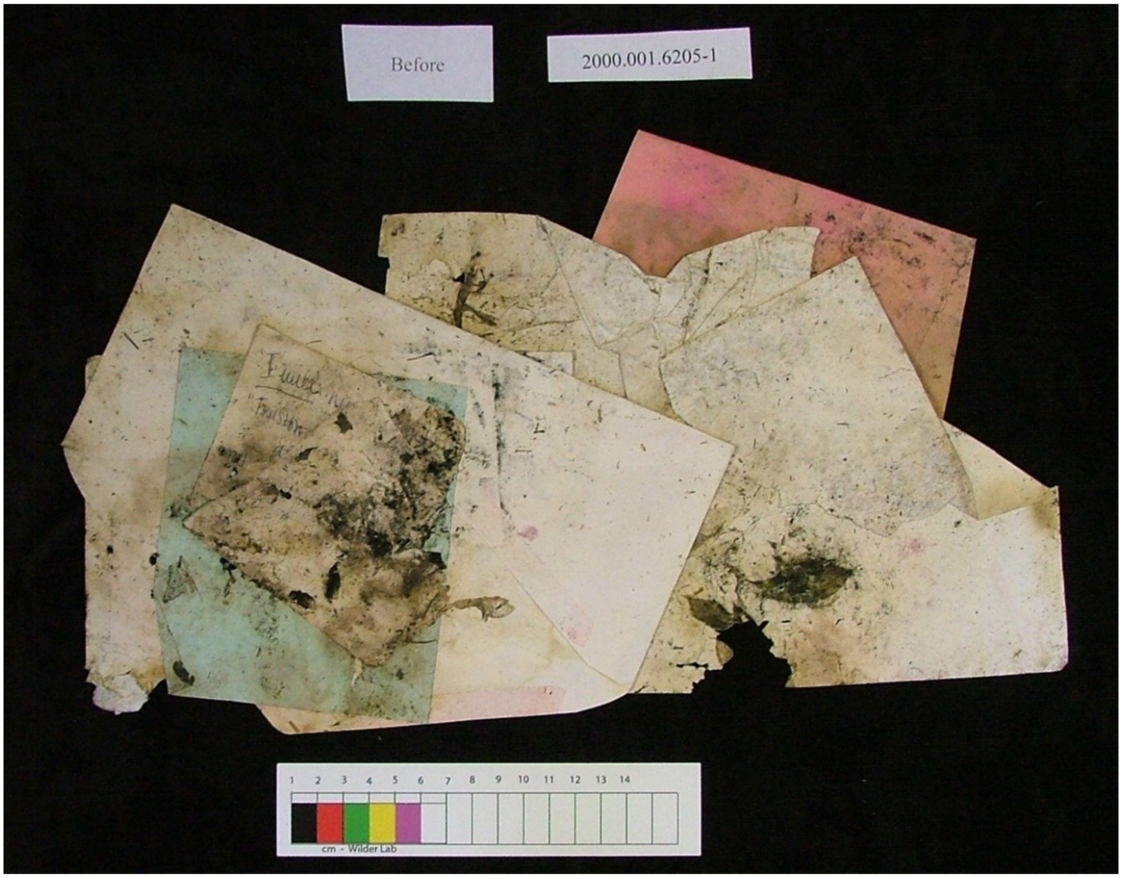

Before
2000.001.6206


Before
2000.001.6206


2000.001.6206
Finished
Twelve Ags Cross the Tracks


2000.001.6206
Finished

Artifact 2000.001.6205 Composite



All of the following artifacts with the numbers 2000.001.6205 a-h were a part of this original composite of papers.

Artifact 2000.001.6205-a

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/25/05 **Artifact No.** 2000.001.6205-a **Initials** ebe

Description and Condition:
1/2 sheet of construction paper "Aggies...Heaven"
surface dirt
mold
fold

Proposed Treatment:
mechanically clean and free from other artifacts
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

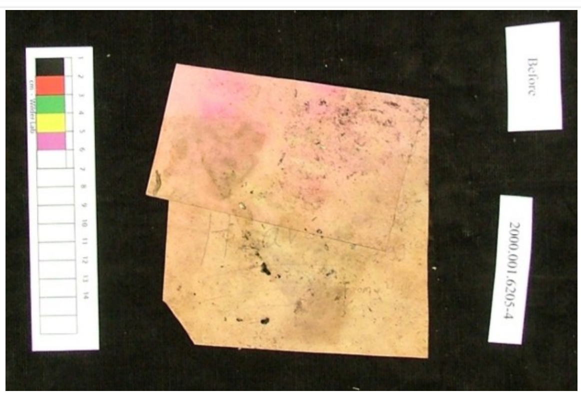
Testing:
ink
lights

Conclusions:
looks and feels great. the artifact was obscured by the group

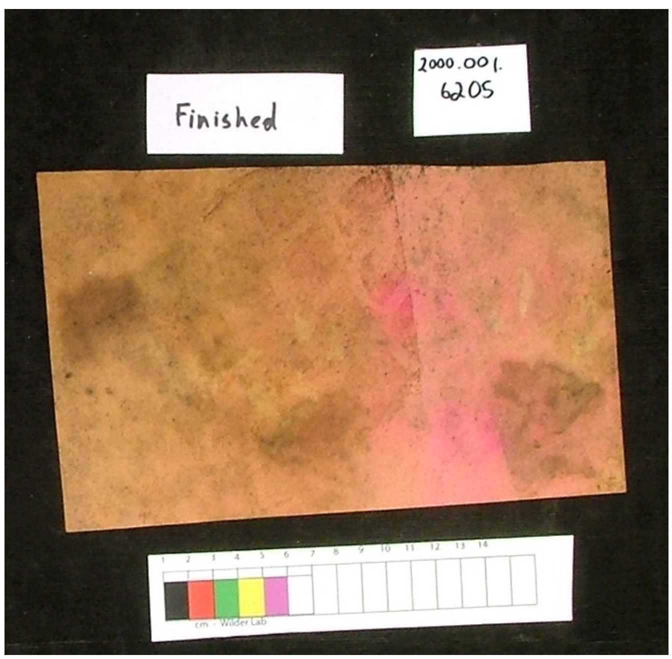
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




Finished
2000.001.
6205
cm - Wilder Lab


Finished
2000.001.
6205
cm - Wilder Lab

Artifact 2000.001.6205-b

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/25/05 **Artifact No.** 2000.001.6205-b **Initials** ebe

Description and Condition:
small envelope-for flowers?
surface dirt
mold
pink staining

Proposed Treatment:
mechanically clean and free from other artifacts
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

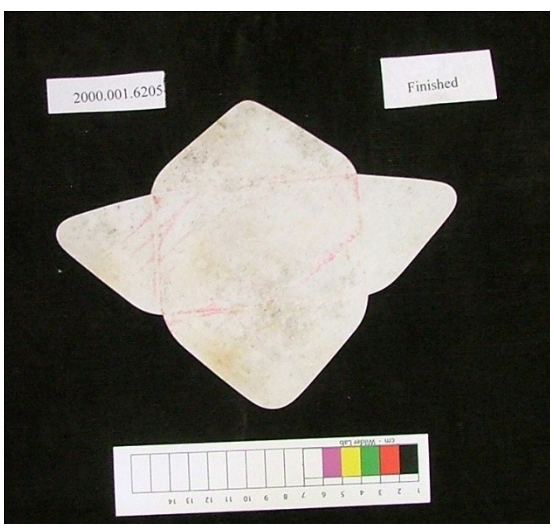
Conclusions:
looks and fells great

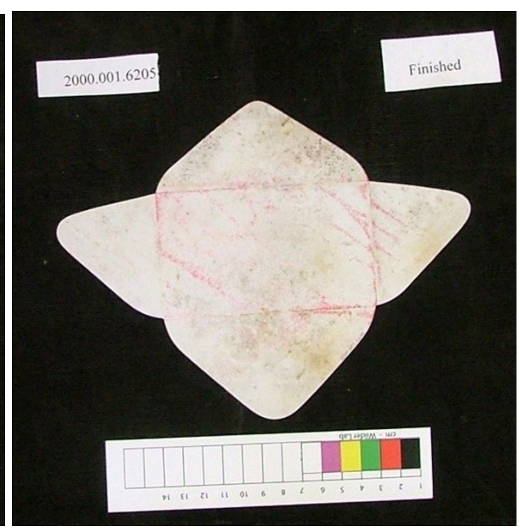
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:

The before photos are missing.





Artifact 2000.0016205-c

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/25/05 **Artifact No.** 2000.001.6205-c **Initials** ebe

Description and Condition:
football ticket
surface dirt
mold

Proposed Treatment:
mechanically clean and free from other artifacts
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

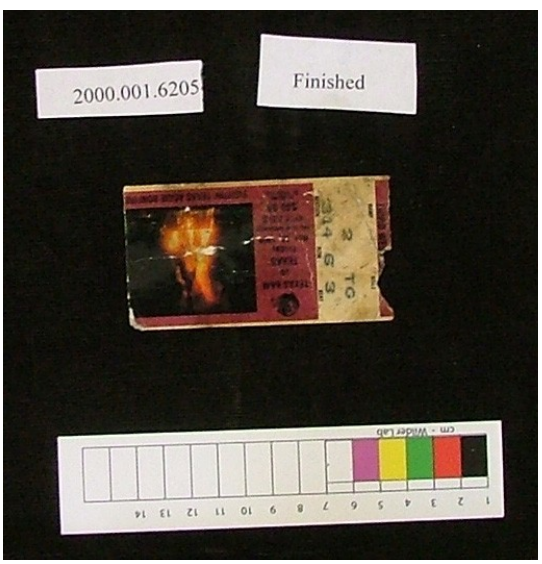
Conclusions:
looks and feels great. While this artifact was not visible in the single group, it was present on the inside

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:

The before photos are missing.



Artifact 2000.0016205-c

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/25/05 **Artifact No.** 2000.001.6205-c **Initials** ebe

Description and Condition:
white sheet of paper
"I don't recall..."
tears rips and small
surface dirt
mold

Proposed Treatment:
mechanically clean and free from other artifacts
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

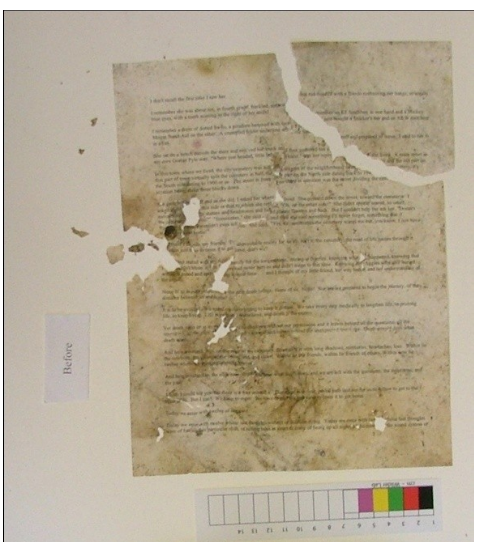
Conclusions:
looks and feels great. While this artifact was not visible in the single group, it was present on the inside

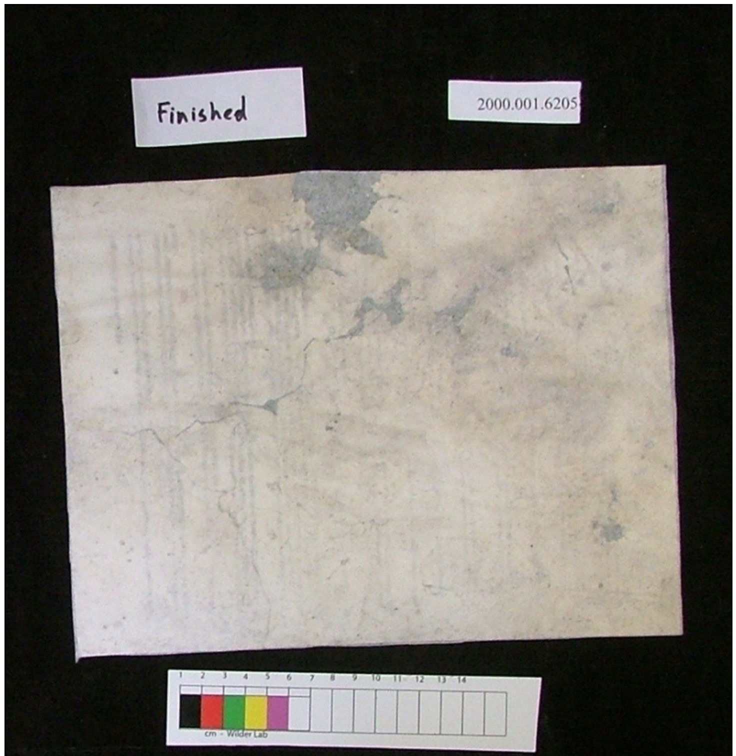
Graphic Record

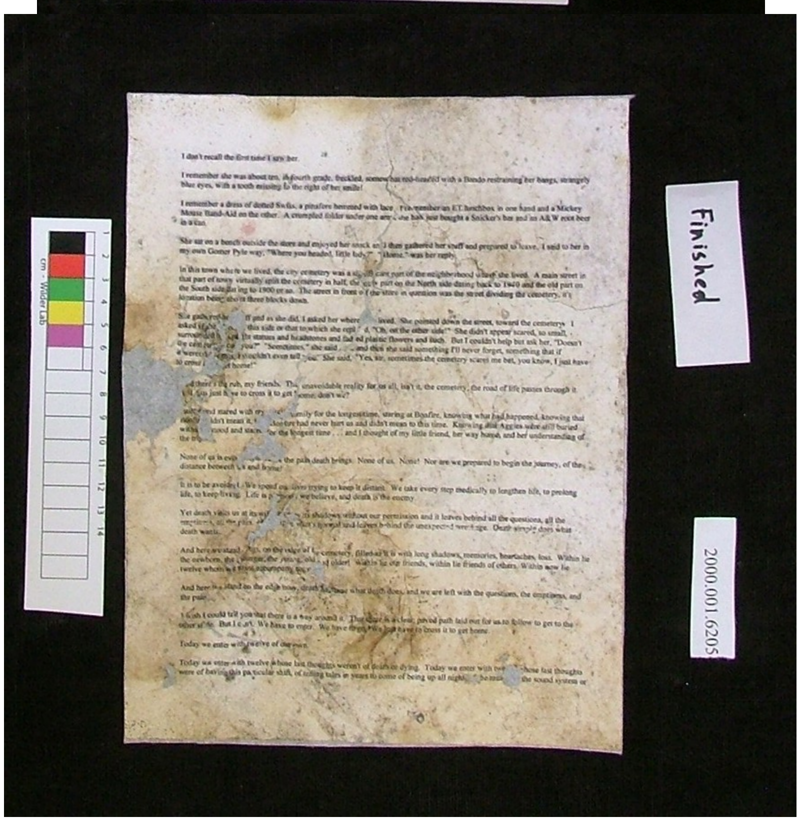
	Before	During	After
Color photo	x		x

Additional Comments:

This report states that it was washed, but it clearly was not washed, but humidified.




Finished
2000.001.6205
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm – Wilder Lab


Finished
2000.001.6205
cm – Wilder Lab

Artifact 2000.001. 6205-e

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/08/05 **Artifact No.** 20000.001.6205.e **Initials** ebe

Description and Condition:
very mangled piece of paper with writing on it
3x7 approx
I Will Never..."
very dirty
brittle
30 pieces

Proposed Treatment:
separate
humidify
clean
humidify
back
humidify
flatten
MTMS/Si`

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
lights
ink

Conclusions:
From the start to the end this artifact looks alot better. It was thought that it would imposible and that that much of it would be recovered, but it looks a lot bettera and can be handled because of the backing.

Graphic Record

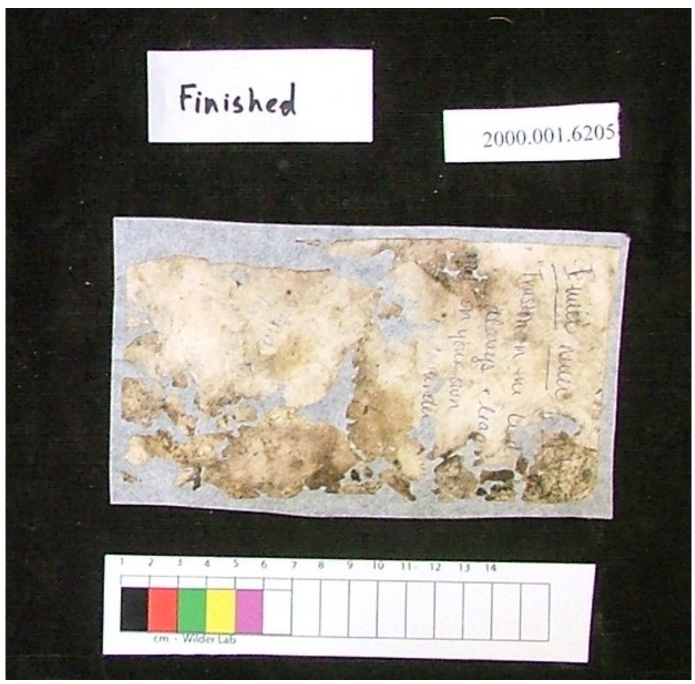
	Before	During	After
Color photo	x	x	x

Additional Comments:

It was a part of this composite group of artifacts.


Finished
2000.001.6205
cm - Wilder Lab


Before


Finished
2000.001.6205
cm - Wilder Lab

Artifact 2000.001.6205-f

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/03/05 **Artifact No.** 2000.001.6205.f **Initials** ebe

Description and Condition:
envelope with "Chad Powell" on it
lots of surface dirt and mold
torn corner
staining

did not contain a letter

Proposed Treatment:
separate
mechanically clean
wash
mend tears
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
lights
ink

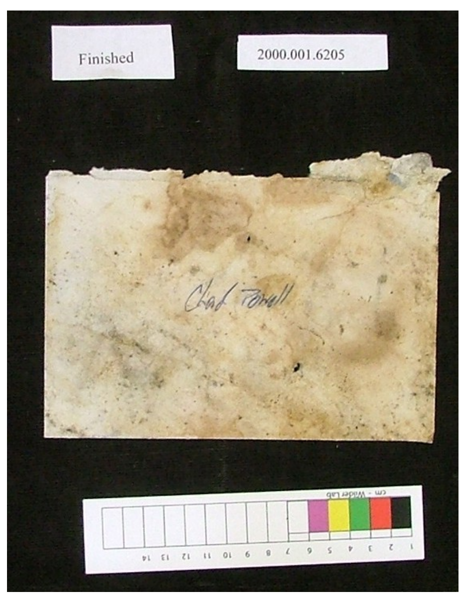
Conclusions:
looked very dirty and brittle before. Needed mend or corner would have come off

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:

The before photos are missing.



Artifact 2000.001.6205-g

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6205g **Initials** ebe

Description and Condition:
4x5 Approx blue paper with xerox ink
"Why?"
very brittle
lots of surface dirt
torn in half from footprint?
hard to handle

Proposed Treatment:
mechanically clean
humidify
clean
humidify
flatten
back
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

Conclusions:
While it is still not that pretty, it looks alot better than it did previously. the backing provided some strength for the artifact, along with the treatment

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6205
Finished
cm - Wilder Lab


2000.001.6205
Finished
cm - Wilder Lab

Artifact 2000.001.6205-h

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/03/05 **Artifact No.** 2000.001.6205.h **Initials** ebe

Description and Condition:
envelope with "Chad Powell" on it
lots of surface dirt and mold
torn leaf
staining

did not contain a letter

Proposed Treatment:
separate
mechanically clean
wash
mend tears
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

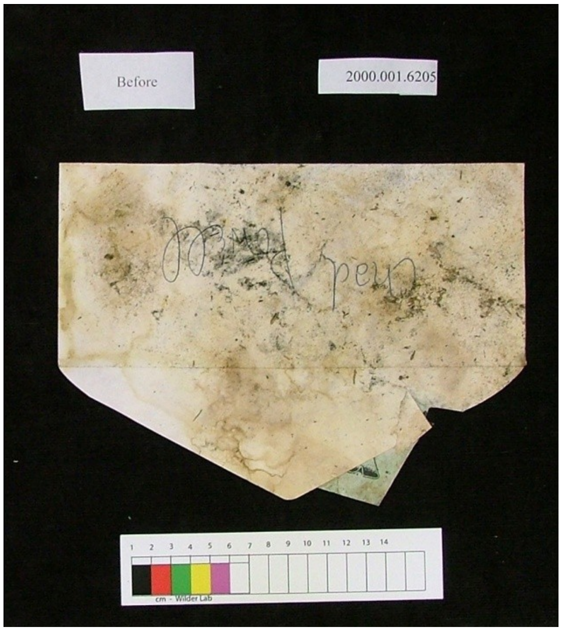
Testing:
lights
ink

Conclusions:
looked very dirty and brittle before.

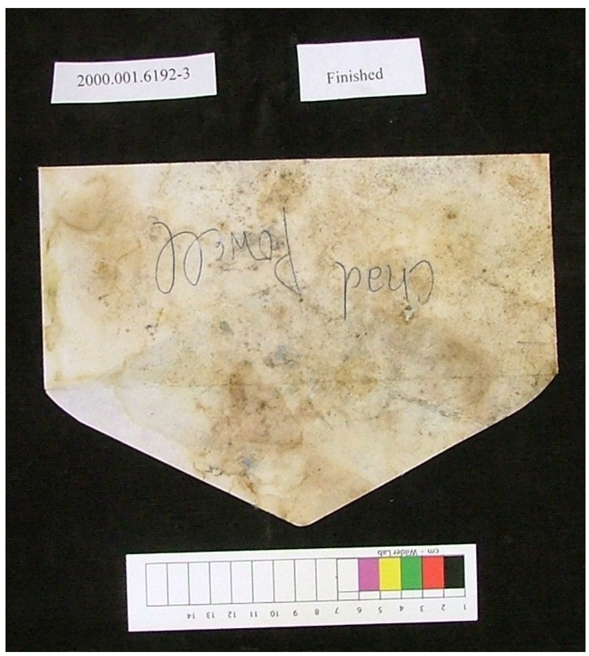
Graphic Record

	Before	During	After
Color photo	x		x

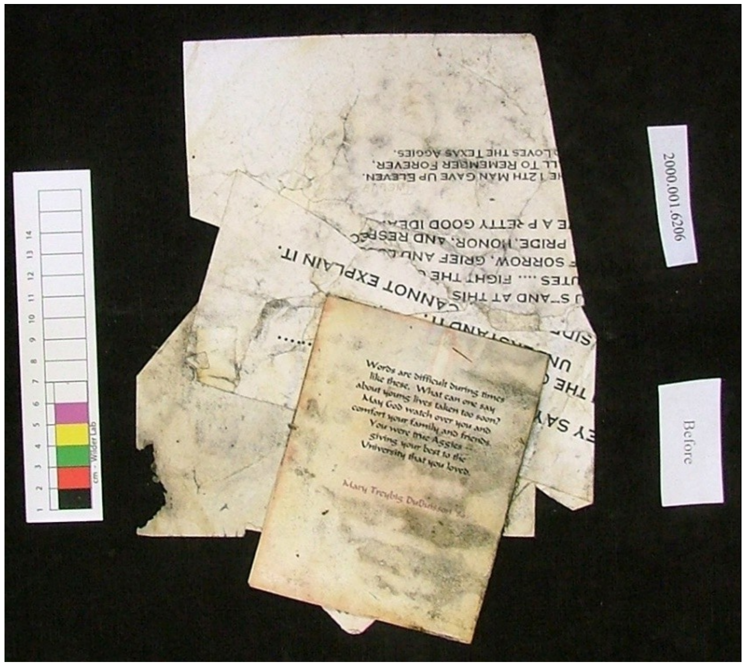
Additional Comments:


Before
2000.001.6205


2000.001.6192-3
Finished


2000.001.6192-3
Finished

Artifact 2000.001.6206
The following artifacts, 6206a-d and f, are from the same composite.



Artifact 2000.001.6206-a

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/05/05 **Artifact No.** 2000.001.6202-a **Initials** ebe

Description and Condition:
white spiral bound notebook paper with 2 or 3 types of ink visible
void in upper corner
thick mold
lots of surface dirt
very fragile and brittle
tears

Proposed Treatment:
mechanically clean
wash
flatten
mend
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

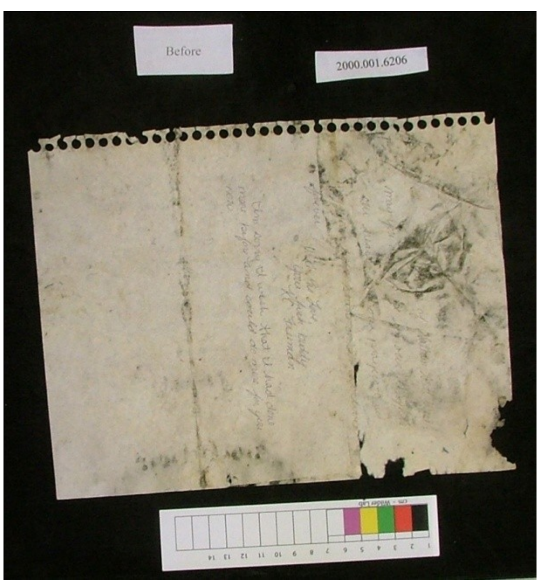
Testing:
ink
light

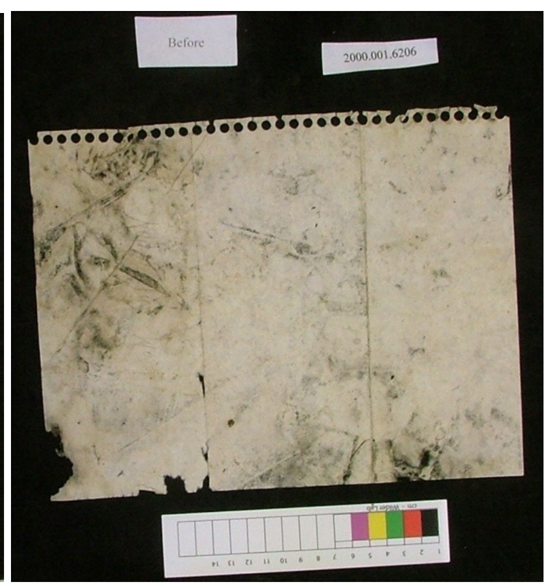
Conclusions:
It was not possible to make out any writing when this was started
Only some tears and voids were filled, to be both as non-invasive as possible and to preserve the intergety of the artifact
can be handled alot more easier, and probably will not cause breathing fits!

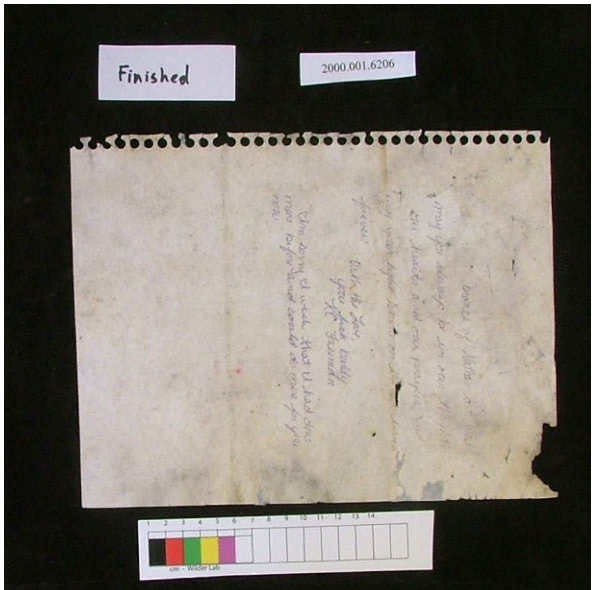
Graphic Record

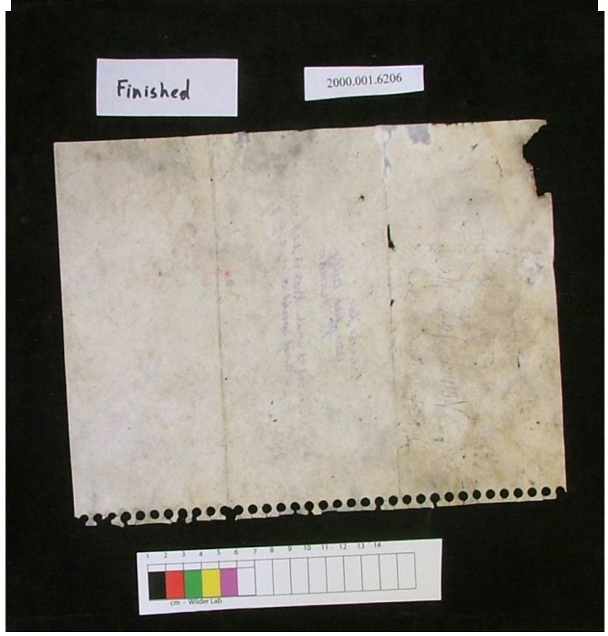
	Before	During	After
Color photo	x		x

Additional Comments:






Finished
2000.001.6206


Finished
2000.001.6206

Artifact 2000.001.6206-b

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/25/05 **Artifact No.** 2000.001.6206b **Initials** ebe

Description and Condition:
football ticket
surface dirt
mold

Proposed Treatment:
mechanically clean and free from other artifacts
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

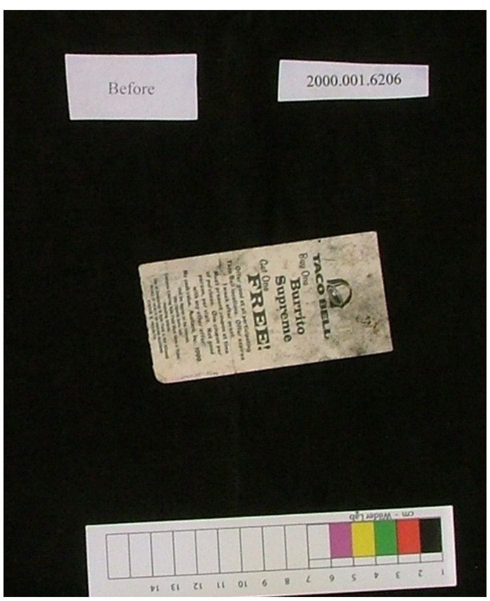
Testing:
ink
lights

Conclusions:
looks and feels great.

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.
6208
NORTH TERRACE BENCH
TEXAS A&M
-VS-
TEXAS
Friday
KYLE FIELD
$40.00
FIGHTIN TEXAS AGGIE BONFIRE
cm - Wilder Lab


2000.001.
6208
TACO BELL
Buy One
Burrito
Supreme
Get One
FREE!
cm - Wilder Lab

Artifact 2000.001.6206-c

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.6206c **Initials** ebe

Description and Condition:
small card for memorial service
folded twice
interior fold stuck together-and inseparable
lots of mold and surface dirt

seam at fold opened during washing

Proposed Treatment:
wash
flatten
mend
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

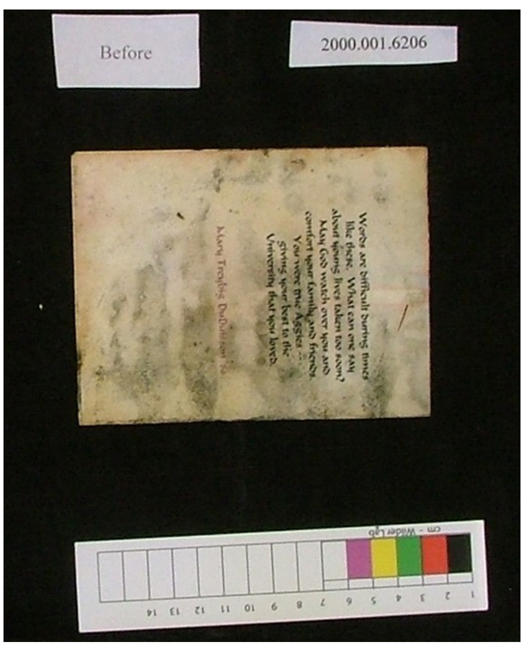
Testing:
ink
lights

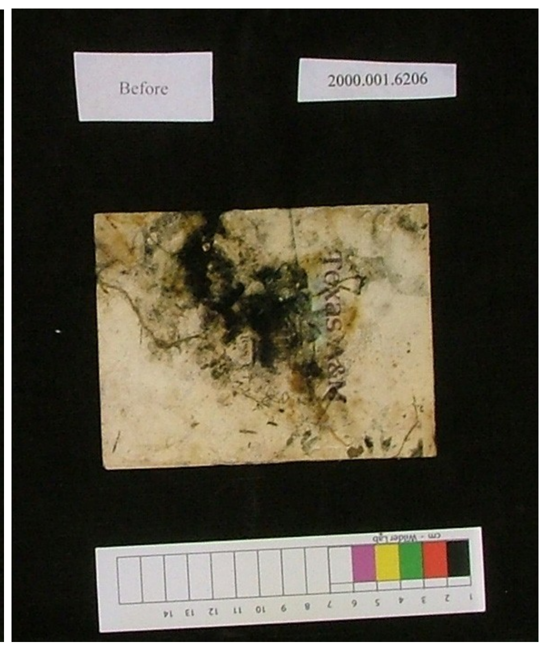
Conclusions:
one can read it and open the card. now the cover is visible from the mold.

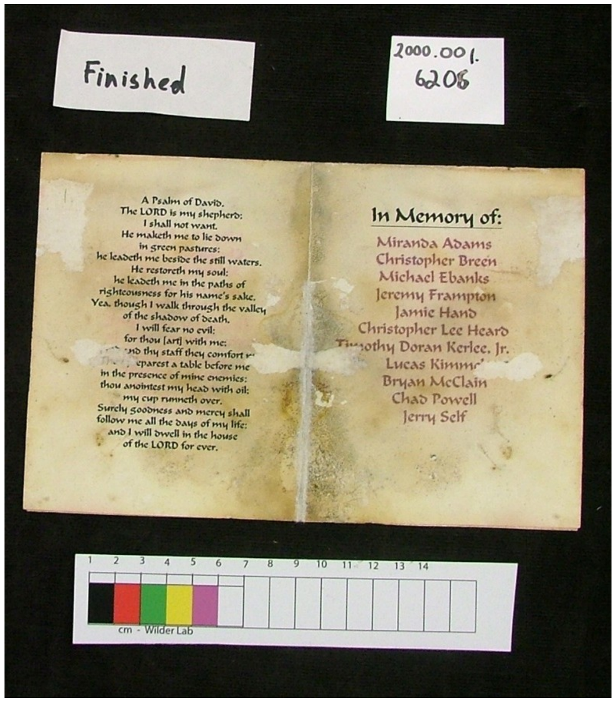
Graphic Record

	Before	During	After
Color photo	x		x

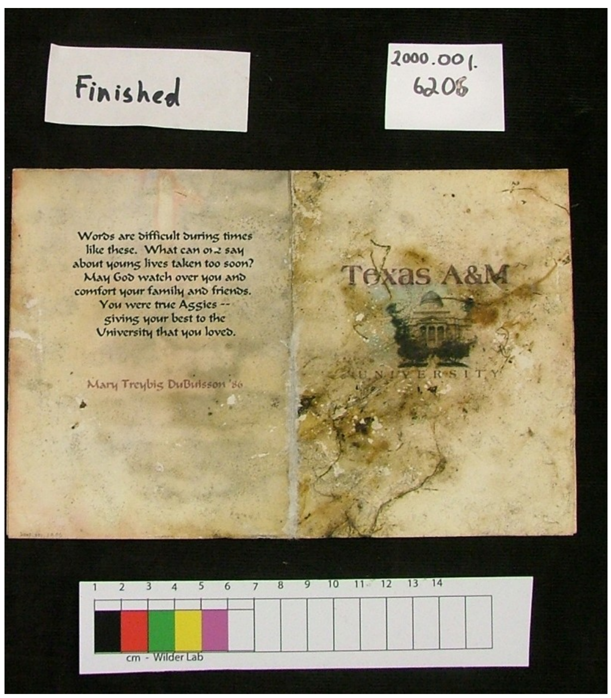
Additional Comments:







Finished
2000.001.
6208
A Psalm of David.
The LORD is my shepherd;
I shall not want.
He maketh me to lie down
in green pastures:
he leadeth me beside the still waters.
He restoreth my soul:
he leadeth me in the paths of
righteousness for his name's sake.
Yea, though I walk through the valley
of the shadow of death,
I will fear no evil:
for thou [art] with me;
in the presence of mine enemies:
thou anointest my head with oil;
my cup runneth over.
Surely goodness and mercy shall
follow me all the days of my life:
and I will dwell in the house
of the LORD for ever.
In Memory of:
Miranda Adams
Christopher Breen
Michael Ebanks
Jeremy Frampton
Jamie Hand
Christopher Lee Heard
Bryan McClain
Chad Powell
Jerry Self
cm - Wilder Lab



Finished
2000.001.
6208
Words are difficult during times
like these. What can one say
about young lives taken too soon?
May God watch over you and
comfort your family and friends.
You were true Aggies --
giving your best to the
University that you loved.
Mary Treybig DuBuisson '86
Texas A&M
cm - Wilder Lab

Artifact 2000.001.6206-f

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/0Th8/05 **Artifact No.** 2000.001.6206f **Initials** ebe

Description and Condition:
White 8.5x11 paper with computer ink
"They say..."
mold
dirt
tears
tape
very fragile
voids

Proposed Treatment:
mechanically clean
remove tape
wash
flatten
back
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

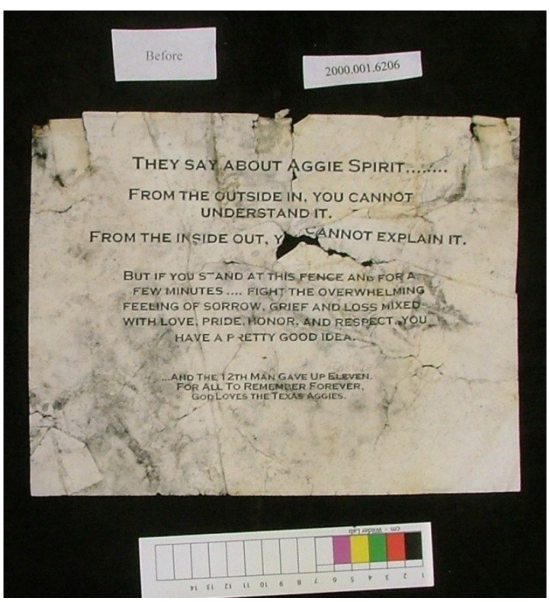
Testing:
ink
light

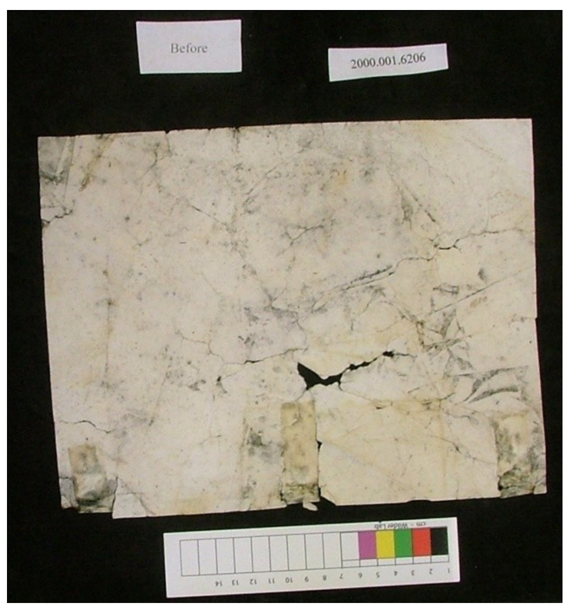
Conclusions:
compared to its begining this document looks a lot better. With the backing it is strong enough to be handled, which it was not before due to all of the rips and the fragility of the paper

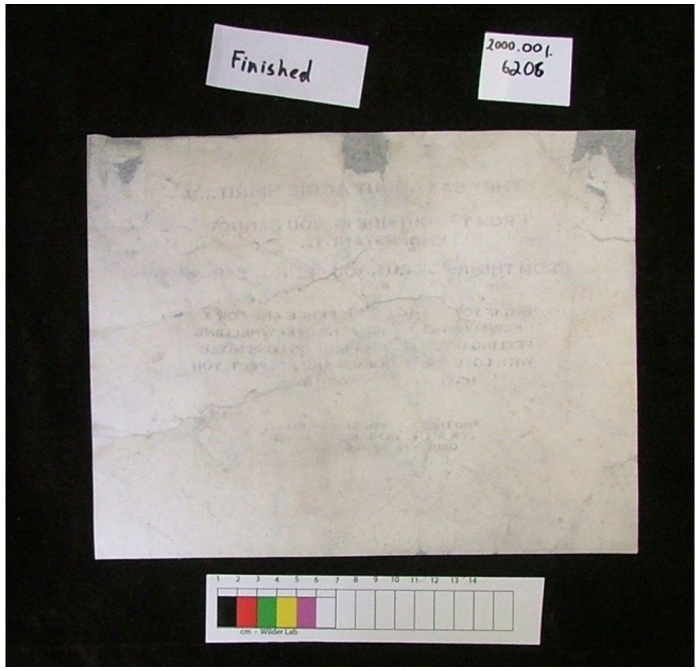
Graphic Record

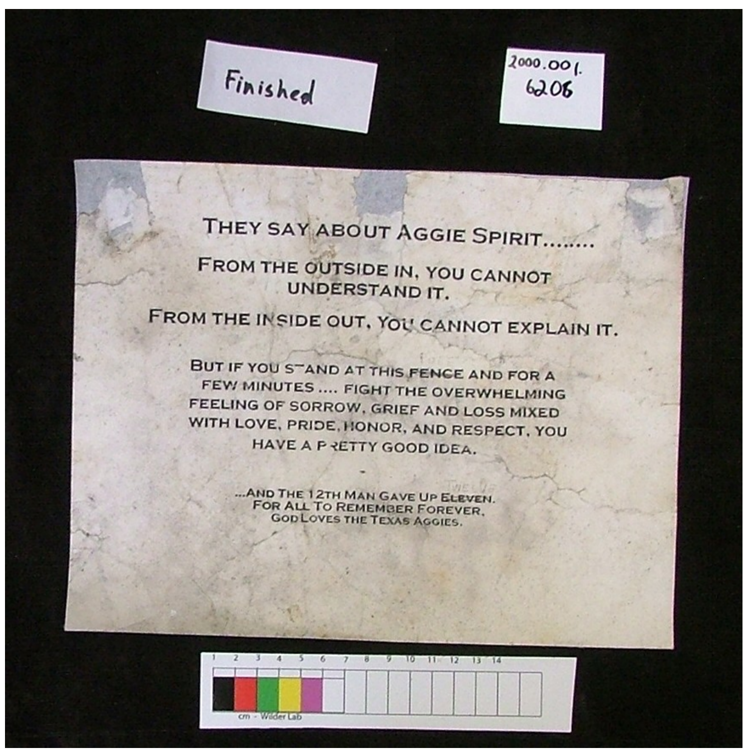
	Before	During	After
Color photo	x		x

Additional Comments:






Finished
2000.001.
6208


Finished
2000.001.
6208
THEY SAY ABOUT AGGIE SPIRIT........
FROM THE OUTSIDE IN, YOU CANNOT UNDERSTAND IT.
FROM THE INSIDE OUT, YOU CANNOT EXPLAIN IT.
BUT IF YOU STAND AT THIS FENCE AND FOR A FEW MINUTES .... FIGHT THE OVERWHELMING FEELING OF SORROW, GRIEF AND LOSS MIXED WITH LOVE, PRIDE, HONOR, AND RESPECT, YOU HAVE A PRETTY GOOD IDEA.
...AND THE 12TH MAN GAVE UP ELEVEN.
FOR ALL TO REMEMBER FOREVER.
GOD LOVES THE TEXAS AGGIES.

Artifact 2000.001.6206-e

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date	12/0Th8/05	**Artifact No.**	2000.001.6206e	**Initials**	ebe

Description and Condition:
White 8.5x11 paper with computer ink
"To the families..."
mold
dirt
tears
very fragile
voids

Proposed Treatment:
mechanically clean
wash
flatten
mend
MTMS/Si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

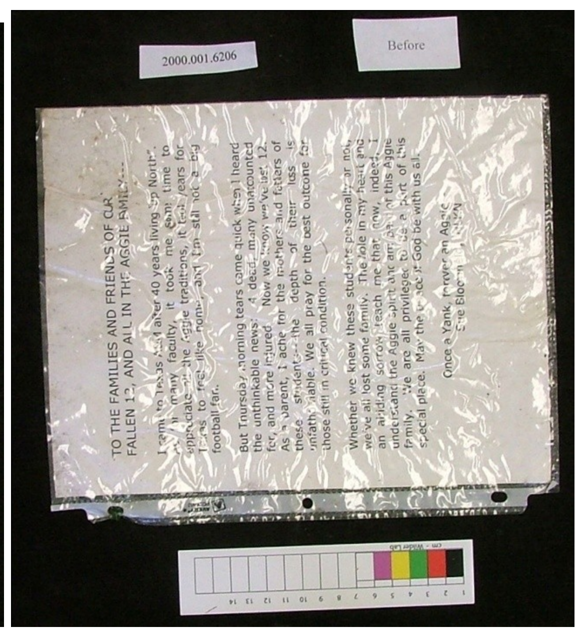
Conclusions:
compared to its begining this document looks a lot better. With the mends it is strong enough to be handled, which it was not before due to all of the rips and the fragility of the paper

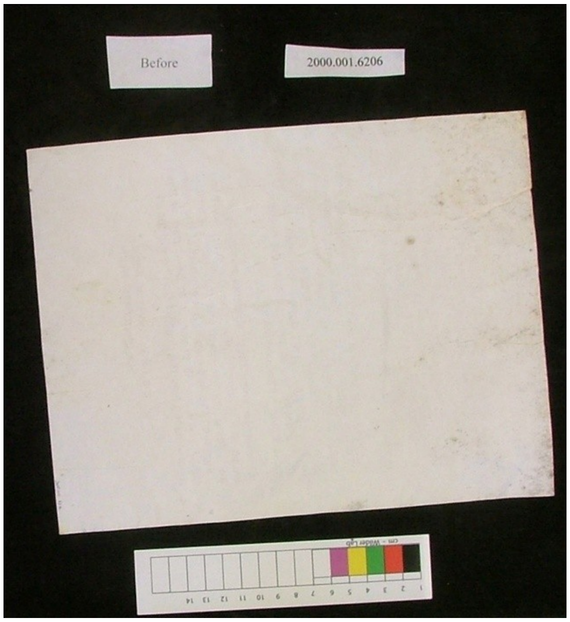
Testing:
ink
light

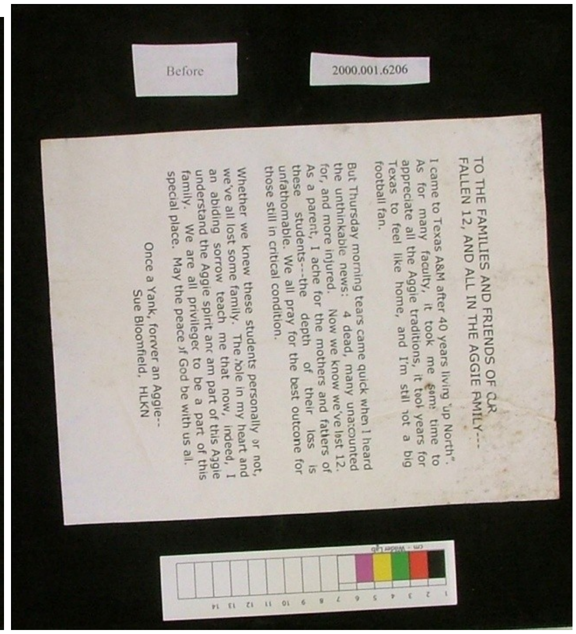
Graphic Record

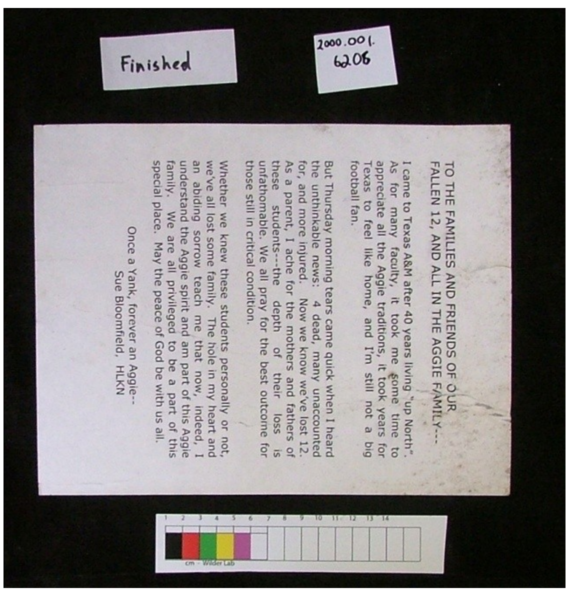
	Before	During	After
Color photo	x		x

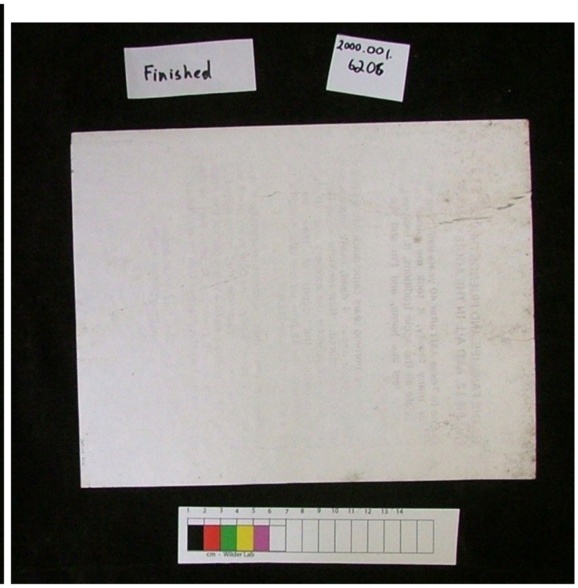
Additional Comments:




Before
2000.001.6206
cm – Wilder Lab


Before
2000.001.6206
TO THE FAMILIES AND FRIENDS OF OUR
FALLEN 12, AND ALL IN THE AGGIE FAMILY---
I came to Texas A&M after 40 years living "up North". As for many faculty, it took me some time to appreciate all the Aggie traditions, it took years for Texas to feel like home, and I'm still not a big football fan.
But Thursday morning tears came quick when I heard the unthinkable news: 4 dead, many unaccounted for, and more injured. Now we know we've lost 12. As a parent, I ache for the mothers and fathers of these students---the depth of their loss is unfathomable. We all pray for the best outcome for those still in critical condition.
Whether we knew these students personally or not, we've all lost some family. The hole in my heart and an abiding sorrow teach me that now, indeed, I understand the Aggie spirit and am part of this Aggie family. We are all privileged to be a part of this special place. May the peace of God be with us all.
Once a Yank, forever an Aggie--
Sue Bloomfield, HLKN
cm – Wilder Lab


Finished
2000.001.
6208
TO THE FAMILIES AND FRIENDS OF OUR
FALLEN 12, AND ALL IN THE AGGIE FAMILY---
I came to Texas A&M after 40 years living "up North". As for many faculty, it took me some time to appreciate all the Aggie traditions, it took years for Texas to feel like home, and I'm still not a big football fan.
But Thursday morning tears came quick when I heard the unthinkable news: 4 dead, many unaccounted for, and more injured. Now we know we've lost 12. As a parent, I ache for the mothers and fathers of these students---the depth of their loss is unfathomable. We all pray for the best outcome for those still in critical condition.
Whether we knew these students personally or not, we've all lost some family. The hole in my heart and an abiding sorrow teach me that now, indeed, I understand the Aggie spirit and am part of this Aggie family. We are all privileged to be a part of this special place. May the peace of God be with us all.
Once a Yank, forever an Aggie--
Sue Bloomfield, HLKN
cm – Wilder Lab


Finished
2000.001.
6208
cm – Wilder Lab

Artifact 2000.001.6206-g

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.6206d **Initials** ebe

Description and Condition:
8.5x11 white paper with computer or xerox print
in acetate
creased
stained
mold
surface dirt

Proposed Treatment:
remove from acetate
wash
flatten
MTMS/si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

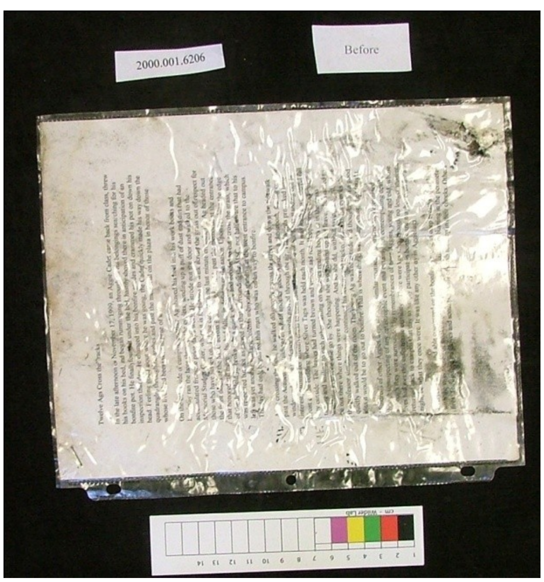
Testing:
ink
light

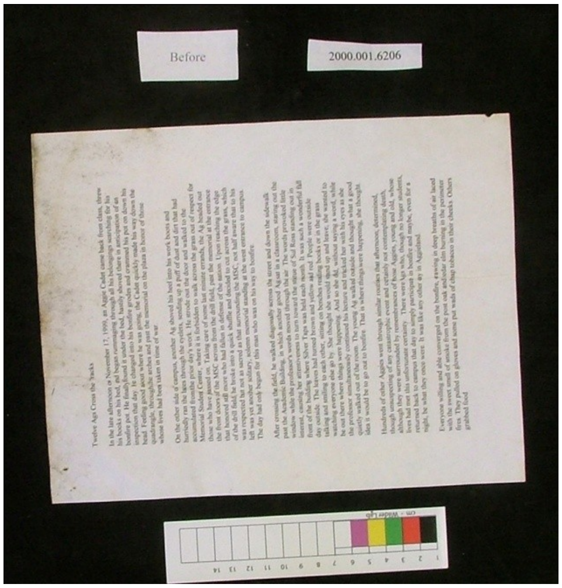
Conclusions:
Frankly, it looks about the same, but it was good to get it out of the acetate and to treat it.

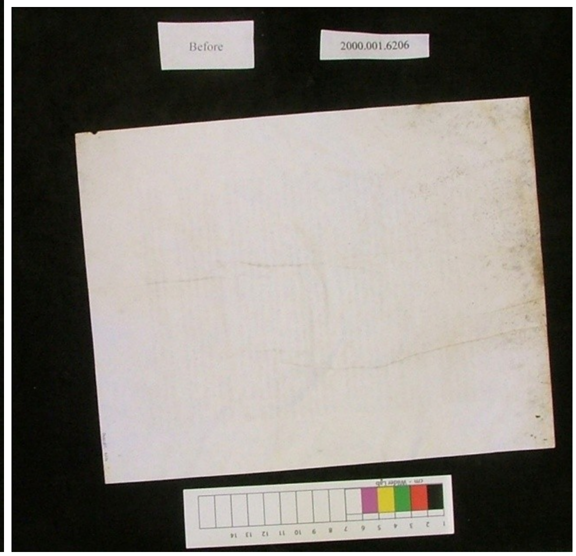
Graphic Record

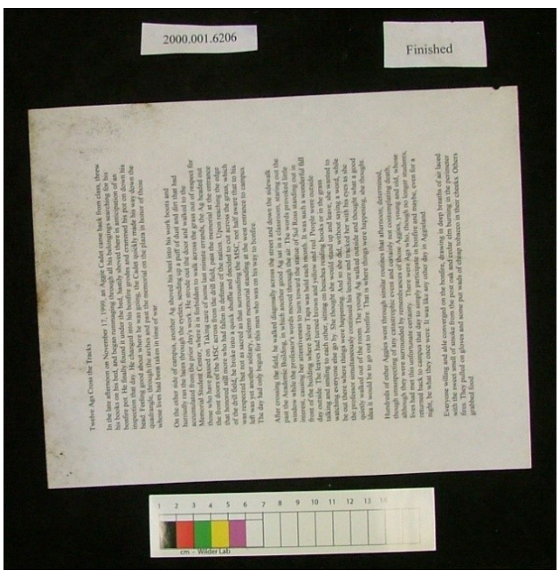
	Before	During	After
Color photo	x		x

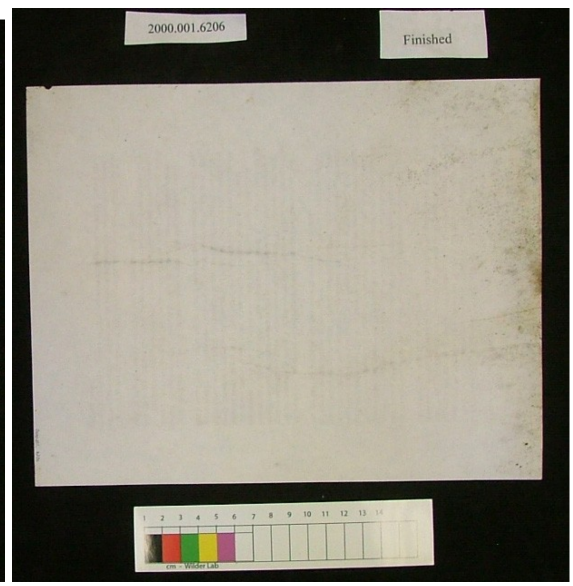
Additional Comments:




Before
2000.001.6206


Before
2000.001.6206


2000.001.6206
Finished


2000.001.6206
Finished

Artifact 2000.001.6207-2

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/20/05 **Artifact No.** 2000.001.6207-2 **Initials** ebe

Description and Condition:
construction paper with three hole punch 10x11
lots of surface dirt
very brittle, esp where concentration of dirt is
once had hand prints in white paint-show up under lights
footstep(s)

Proposed Treatment:
mechanically clean
humidify
flatten
mend
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

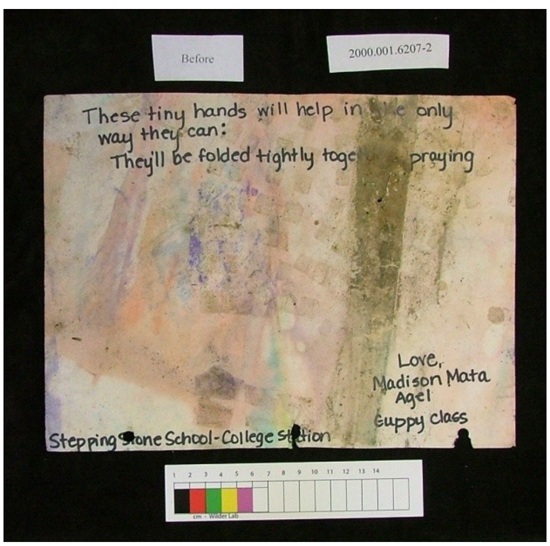
Testing:
ink-non soluble
lights-show hand prints

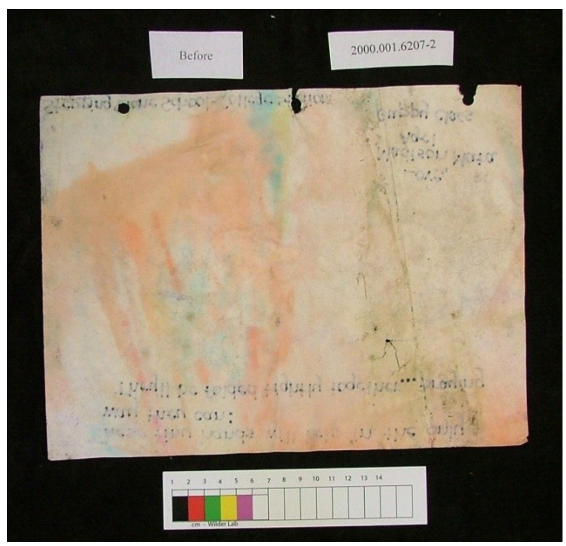
Conclusions:
looks better, it was very fragile, especially where the dirt had been ground in
the tree punch holes were torn, and should be handled carefully
not so brittle and very flexible

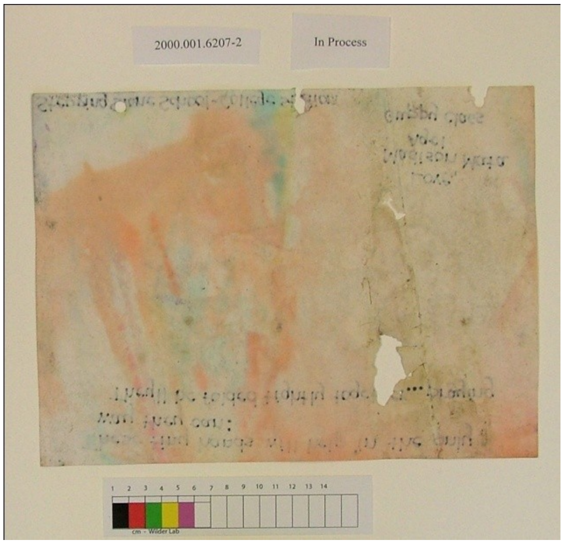
Graphic Record

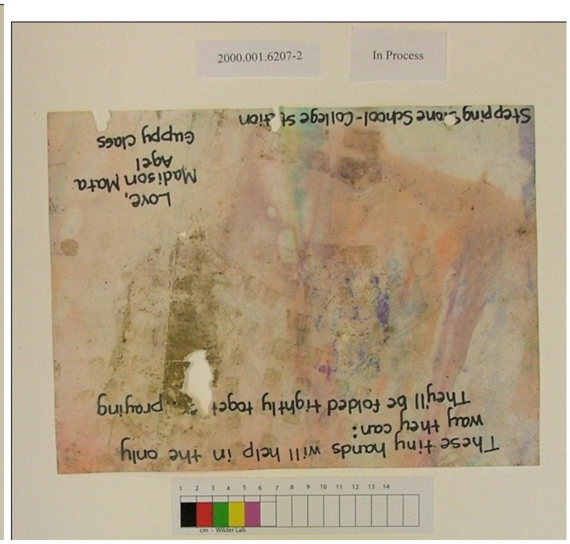
	Before	During	After
Color photo	x		x

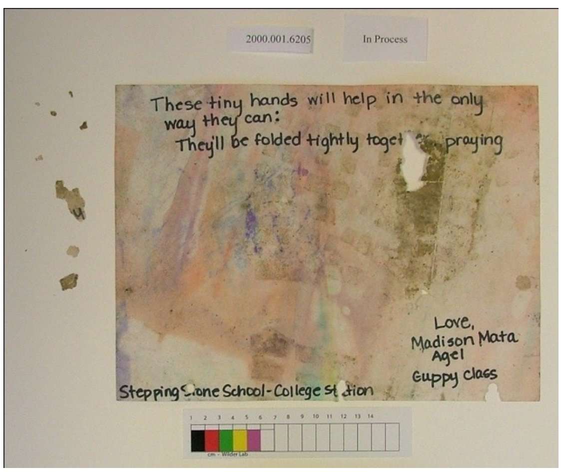
Additional Comments: the photos may have the wrong number on them, but they belong to this report

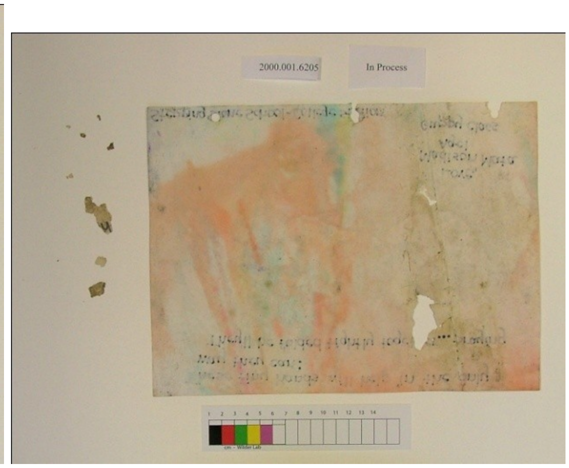


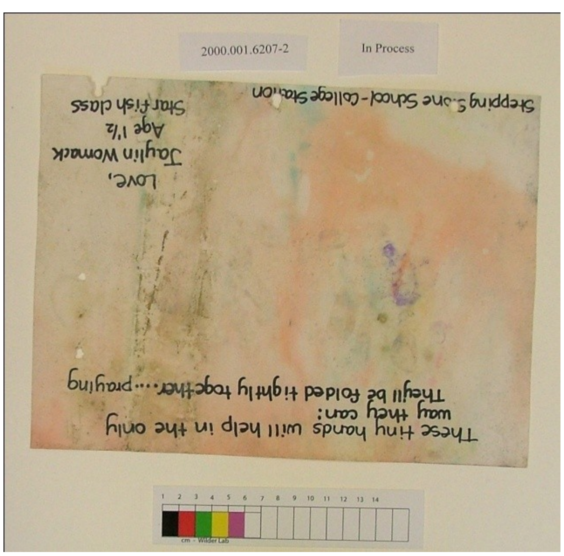


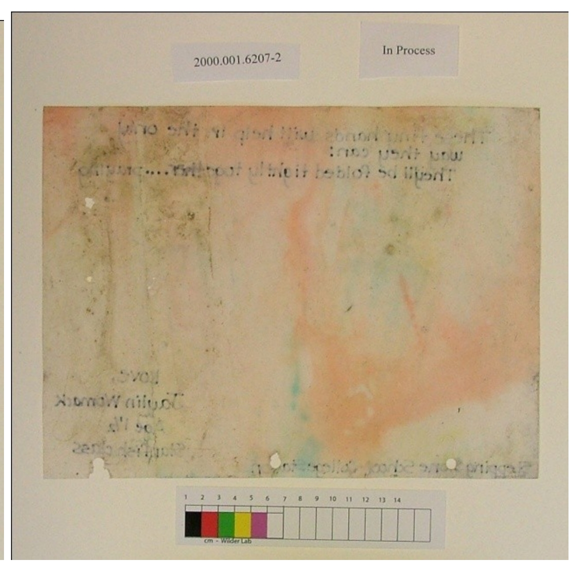

2000.001.6207-2
In Process


2000.001.6207-2
In Process
These tiny hands will help in the only
way they can:
They'll be folded tightly toget... praying
Love,
Madison Mata
Age1
Guppy class
Stepping S..one School-College st..tion

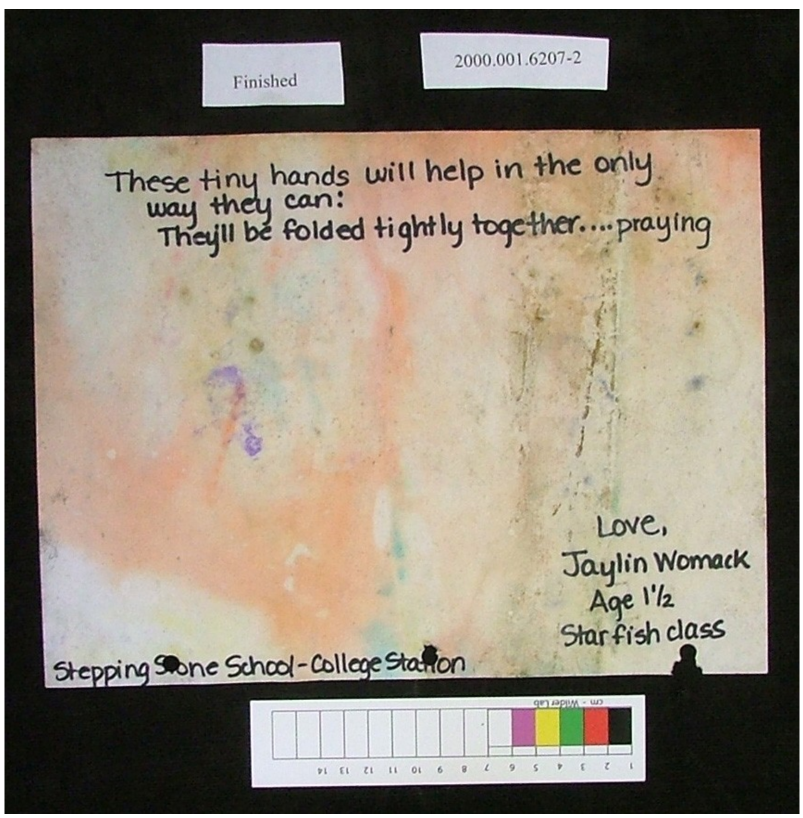

2000.001.6205
In Process
These tiny hands will help in the only
way they can:
They'll be folded tightly toget... praying
Love,
Madison Mata
Age1
Guppy class
Stepping S..one School-College st..tion


2000.001.6205
In Process


2000.001.6207-2
In Process
These tiny hands will help in the only
way they can:
They'll be folded tightly together....praying
Love,
Jaylin Womack
Age 1½
Starfish class
Stepping S..one School-College Station


2000.001.6207-2
In Process


Finished
2000.001.6207-2


Finished
2000.001.6207-2
These tiny hands will help in the only
way they can:
They'll be folded tightly together....praying
Love,
Jaylin Womack
Age 1½
Star fish class
Stepping Stone School-College Station

Artifact 2000.001.6208

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/5/05 **Artifact No.** 2000.001.6208 **Initials** ebe

Description and Condition:
construction paper card-green or yellow
"God bless Aggies"
lots of surface dirt
mold

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

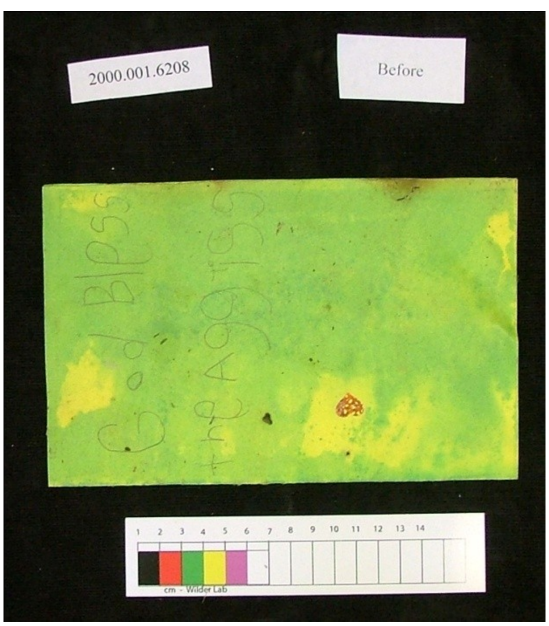
Testing:
ink
lights

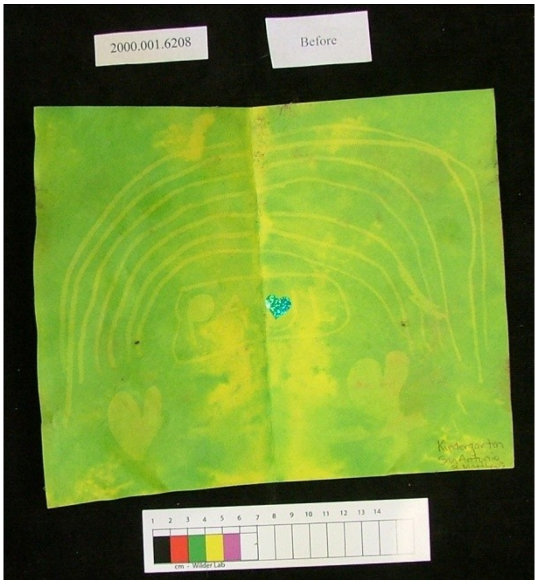
Conclusions:
looks lots better and is much stronger

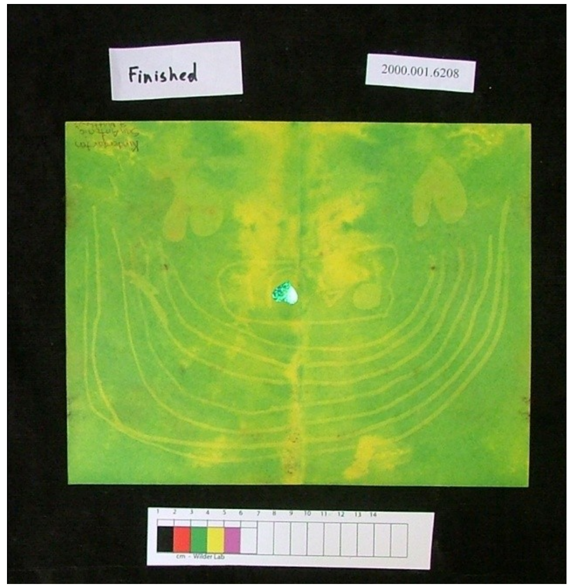
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.6208
Before


Finished
2000.001.6208


Finished
2000.001.6208

Artifact 2000.001.6209

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/7/05 **Artifact No.** 2000.001.6209 **Initials** ebe`

Description and Condition:
card from Timothy Kerlee
ink run
lots of surface dirt
small tear on seam

Proposed Treatment:
mechanically clean
wash
flatten
mend
MTMS/SI

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

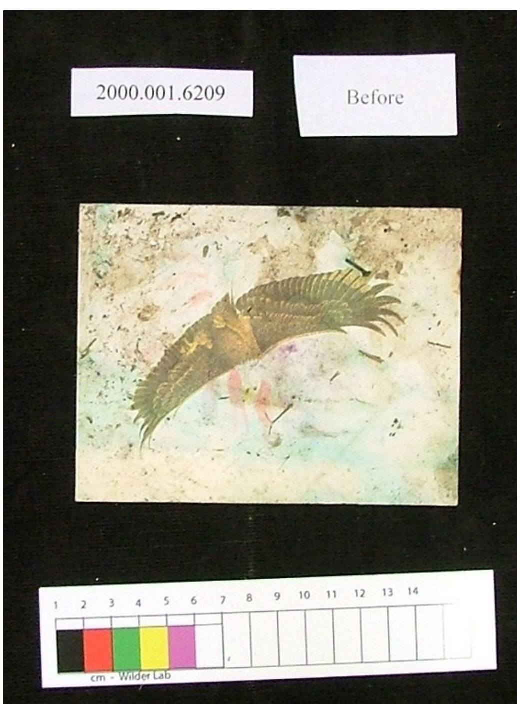
Testing:
ink
lights

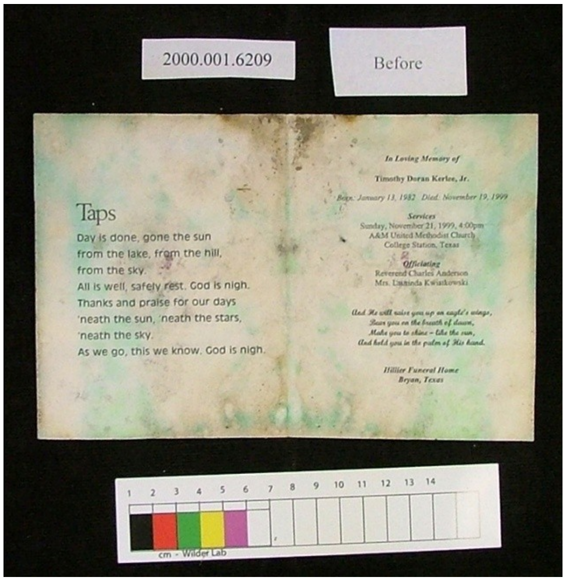
Conclusions:
looks better and is more flexible

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




2000.001.6209
Before
Taps
Day is done, gone the sun
from the lake, from the hill,
from the sky.
All is well, safely rest. God is nigh.
Thanks and praise for our days
'neath the sun, 'neath the stars,
'neath the sky.
As we go, this we know. God is nigh.
In Loving Memory of
Timothy Doran Kerlee, Jr.
Born: January 13, 1982 Died: November 19, 1999
Services
Sunday, November 21, 1999, 4:00pm
A&M United Methodist Church
College Station, Texas
Officiating
Reverend Charles Anderson
Mrs. Laurinda Kwiatkowski
And He will raise you up on eagle's wings,
Bear you on the breath of dawn,
Make you to shine – like the sun,
And hold you in the palm of His hand.
Hillier Funeral Home
Bryan, Texas
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab


Finished
2000.001.6209
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab


Finished
2000.001.6209
Taps
Day is done, gone the sun
from the lake, from the hill,
from the sky.
All is well, safely rest. God is nigh.
Thanks and praise for our days
'neath the sun, 'neath the stars,
'neath the sky.
As we go, this we know. God is nigh.
In Loving Memory of
Timothy Doran Kerlee, Jr.
Born: January 13, 1982 Died: November 19, 1999
Services
Sunday, November 21, 1999, 4:00pm
A&M United Methodist Church
College Station, Texas
Officiating
Reverend Charles Anderson
Mrs. Laurinda Kwiatkowski
Hillier Funeral Home
Bryan, Texas
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab

Artifact 2000.001.6210

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/05/05 **Artifact No.** 2000.001.6210 **Initials** ebe

Description and Condition:
construction paper card
St. Matthews kindergarten
lots of surface dirt and mold
vegetation
2 stickers
2 voids on edge

Proposed Treatment:
wash
flatten
mend/fill
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

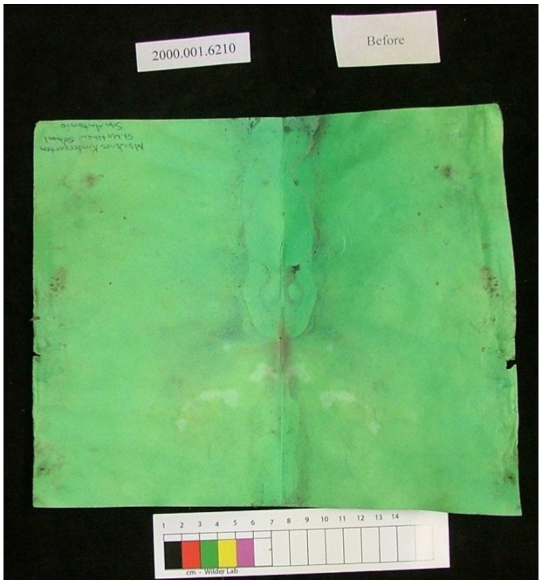
Testing:
Light
Ball point in safe

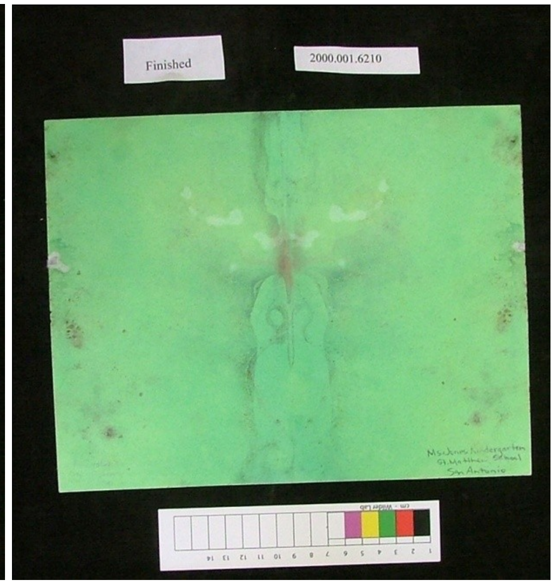
Conclusions:
looks much better with cleaning
stronger from MTMS/Si

Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6210
Before
cm – Wilder Lab


Finished
2000.001.6210


Finished
2000.001.6210

Artifact 2000.001.6211

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.6212 **Initials** ebe

Description and Condition:
sealed letter in white envelop-legal size
"To an Aggie" in pencil on one side
God Bless... on other
White paper 8.5x11
"I am sorry, Happy birthday...." in pencil
blue ink run

Proposed Treatment:
open envelope using ethanol
humidify
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

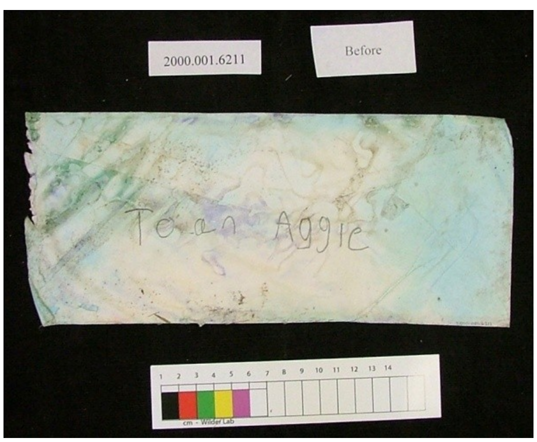
Testing:
ink
light

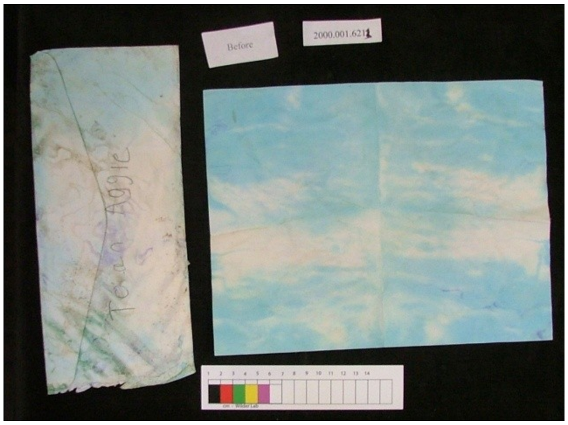
Conclusions:
looks better and is more flexible

Graphic Record

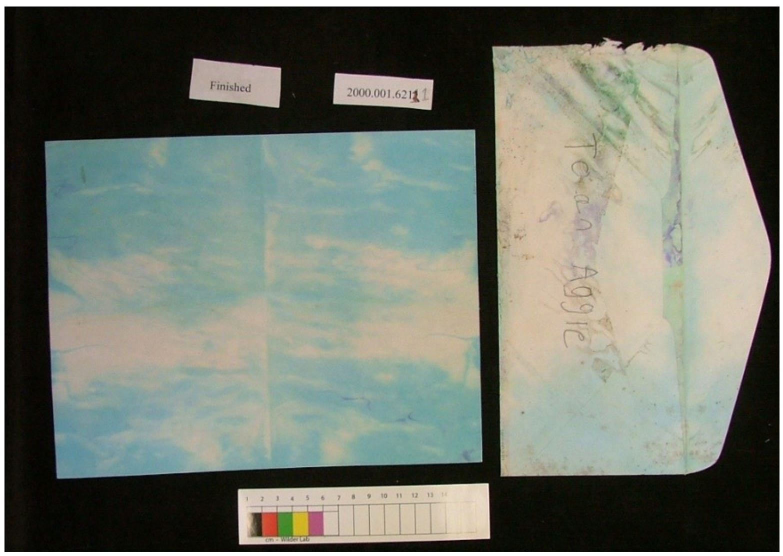
	Before	During	After
Color photo	x	x	x

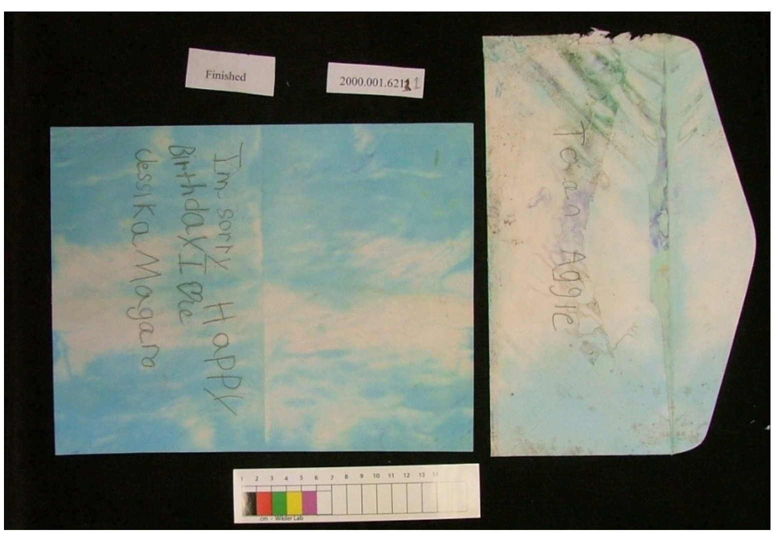
Additional Comments:




Before
2000.001.621


Before
2000.001.621


Finished
2000.001.621


Finished
2000.001.621

Artifact 2000.001.6212

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.6212 **Initials** ebe

Description and Condition:
sealed letter in white envelop-legal size
"Diannna" in pencil
White paper 8.5x11
"bless" in pencil
blue ink run

Proposed Treatment:
open envelope using ethanol
humidify
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

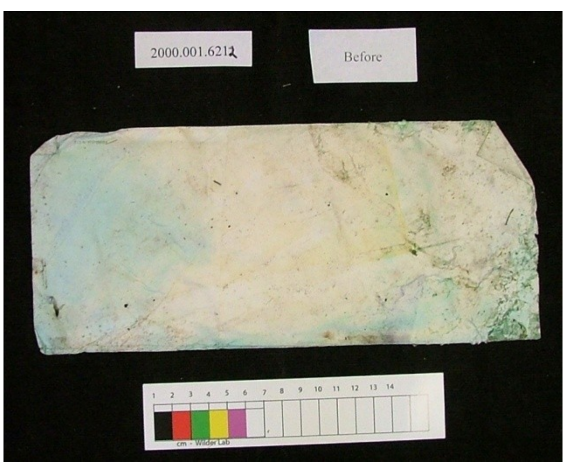
Testing:
ink
light

Conclusions:
looks better and is more flexible

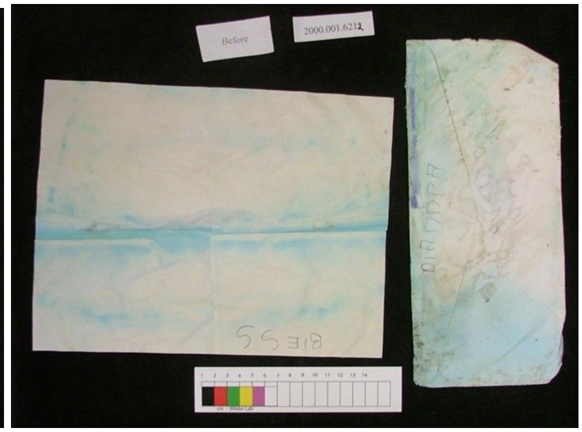
Graphic Record

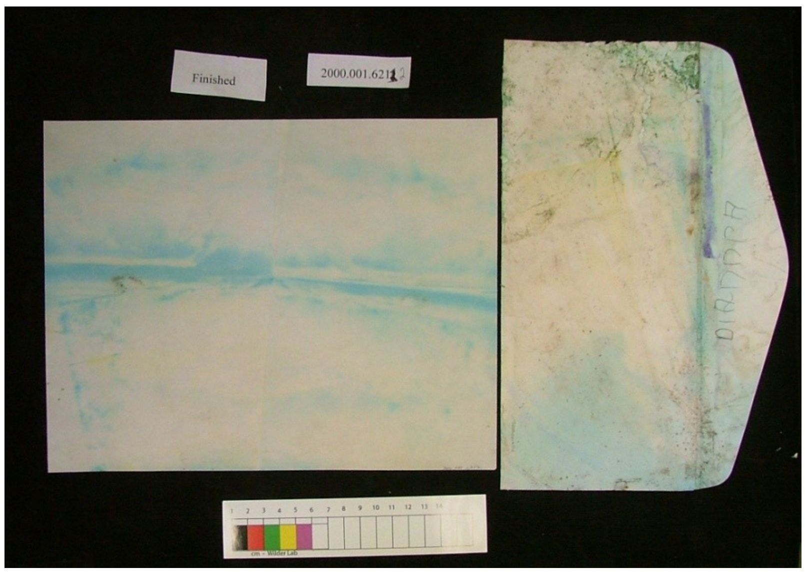
	Before	During	After
Color photo	x	x	x

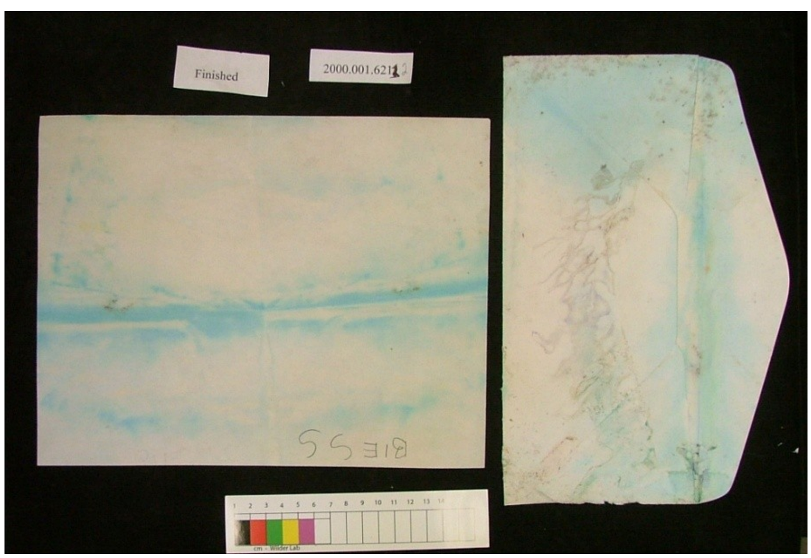
Additional Comments:




Before
2000.001.6212


Before
2000.001.6212


Finished
2000.001.6212


Finished
2000.001.6212

Artifact 2000.001.6213

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/25/05 **Artifact No.** 2000.001.6213 **Initials** ebe

Description and Condition:
football ticket
surface dirt
mold
ribbon
stick pin

Proposed Treatment:
mechanically clean and free from other artifacts
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

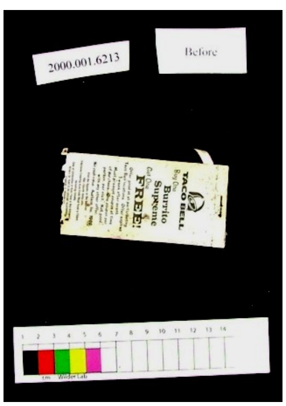
Testing:
ink
lights

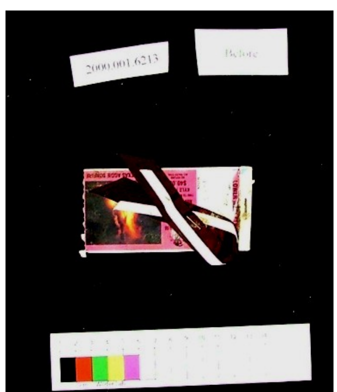
Conclusions:
looks and feels great. The pictures do a disservice as the before it is washed out and the after is too dark.

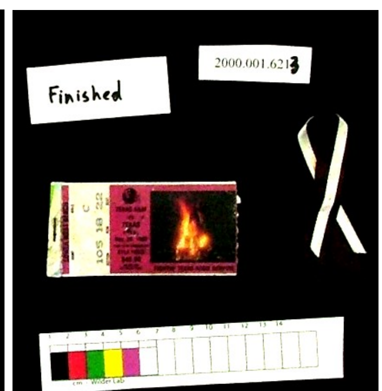
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:







Artifact 2000.001.6214

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.6214 **Initials** ebe

Description and Condition:
note card for flowers
ball point ink on both sides
surface dirt and mold

Proposed Treatment:
wash
flatten
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

Testing:
ink
lights

Conclusions:
looks better ant the writing is faint but readable

Graphic Record

	Before	During	After
Color photo			x

Additional Comments:
lost the before pictures-no idea?

No before photo

Artifact 2000.001.6216

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 12/09/05 **Artifact No.** 2000.001.6216 **Initials** ebe

Description and Condition:
glossy printed card for party, rave, or other function
surface dirt
stiff

Proposed Treatment:
Mechanically clean
wash
MTMS/Si

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

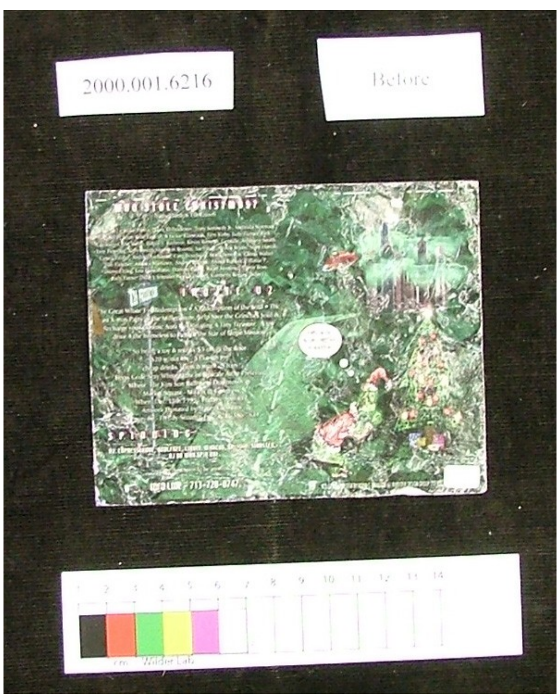
Testing:
ink
lights

Conclusions:
looks better after cleaning and not so stiff

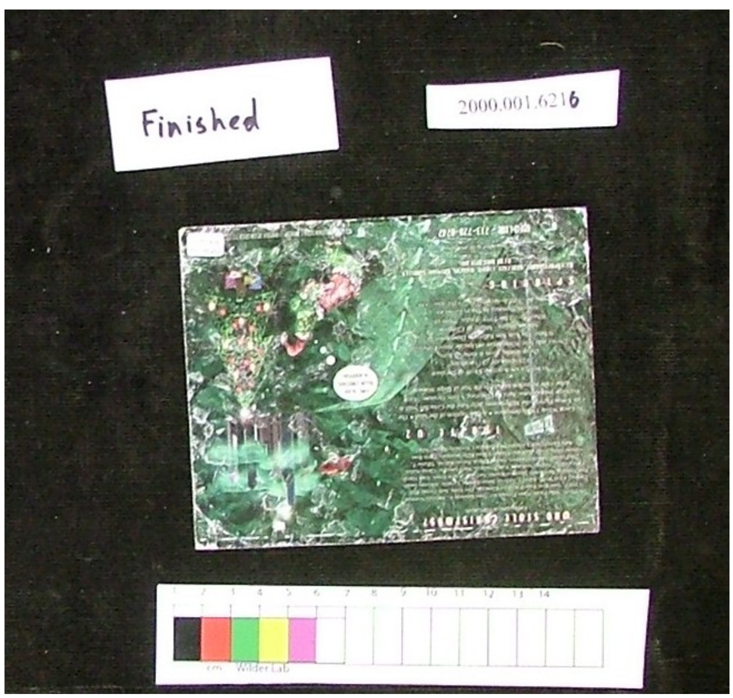
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:




Finished
2000.001.6216
NEW YEARS EVE MILLENNIUM PARTY
FOR MORE INFO CALL
713-720-0747
cm Wilder Lab


Finished
2000.001.6216
cm Wilder Lab

Artifact 2000.001.6217

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/18/05 **Artifact No.** 2000.001.6217 **Initials** ebe

Description and Condition:
5.5X9" (approx) Stationary
ball point pen
3 hearts in crayon
pen ink
surface dirt
mold

Proposed Treatment:
Wash
Flatten
MTMS/Si treatment

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

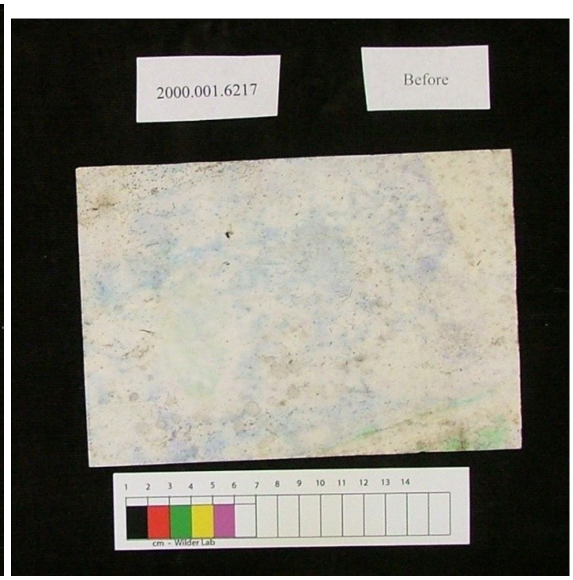
Testing:
lights - UVA shows both a blue and a green glow. The green seems linked to a green crayon. The blue may be the run off of another ink.

Conclusions:
After treatment, it looks a lot better. It is now readable in some places. If scanned, it may be even more readable,

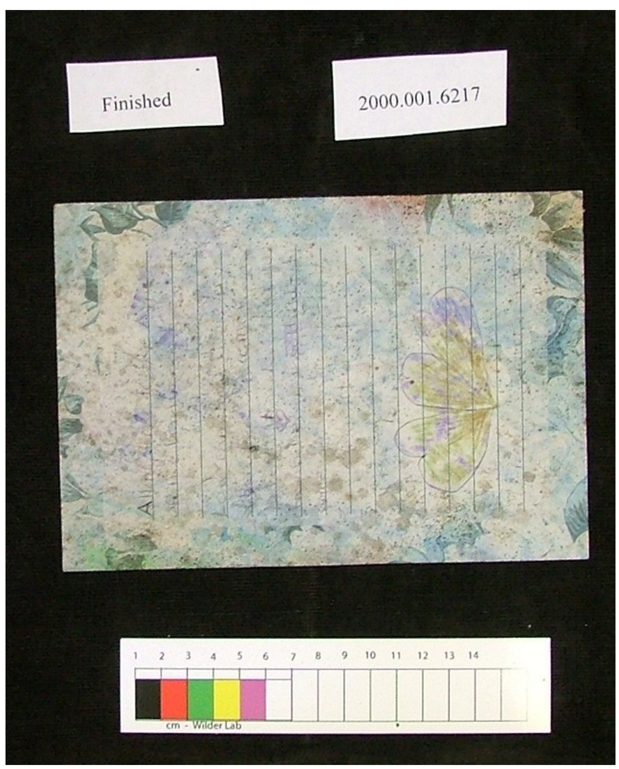
Graphic Record

Color photo Before During After

Additional Comments:




Finished
2000.001.6217
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab


Finished
2000.001.6217
1 2 3 4 5 6 7 8 9 10 11 12 13 14
cm - Wilder Lab

Artifact 2000.001.6218

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/5/05 **Artifact No.** 2000.001.6218 **Initials** ebe

Description and Condition:
construction paper card
"God bless the aggies I love you" in pencil

Proposed Treatment:
humidify
flatten
MTMS/si

Retreat with 100%MTMS`

Results: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

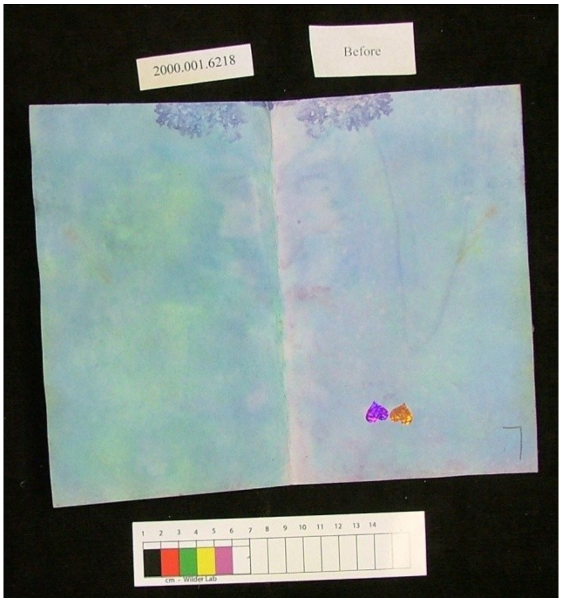
Testing:
h2o soluble ink
Lights-nothing

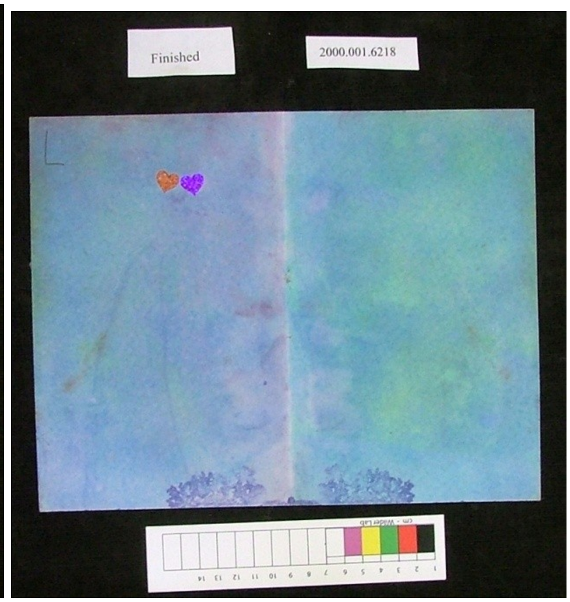
Conclusions:
after treatment, it was decided that it should be retreated.
This lightened it up and made the paper more pliable

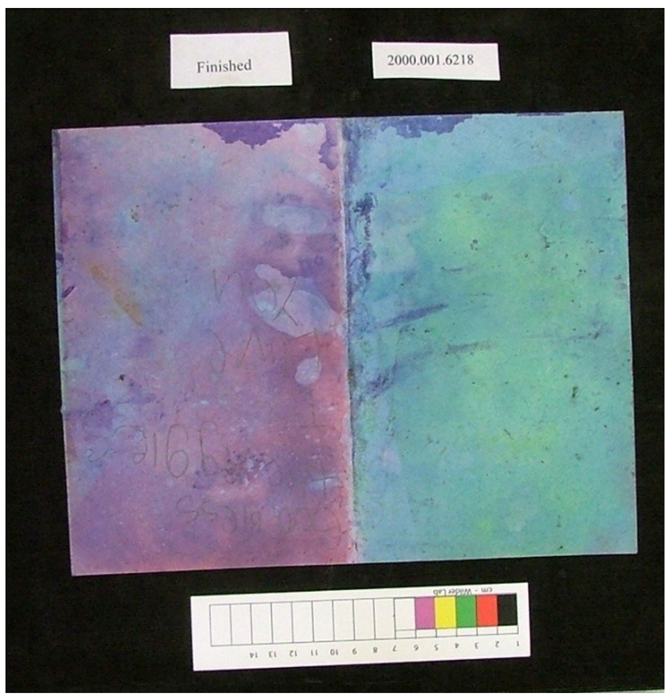
Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:


2000.001.6218
Before


Finished
2000.001.6218


Finished
2000.001.6218

Artifact 2000.001.6219

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/5/05 **Artifact No.** 2000.001.6219 **Initials** ebe

Description and Condition:
construction paper card-green
lots of surface dirt
mold

Proposed Treatment:
mechanically clean
wash
flatten
MTMS/Si

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

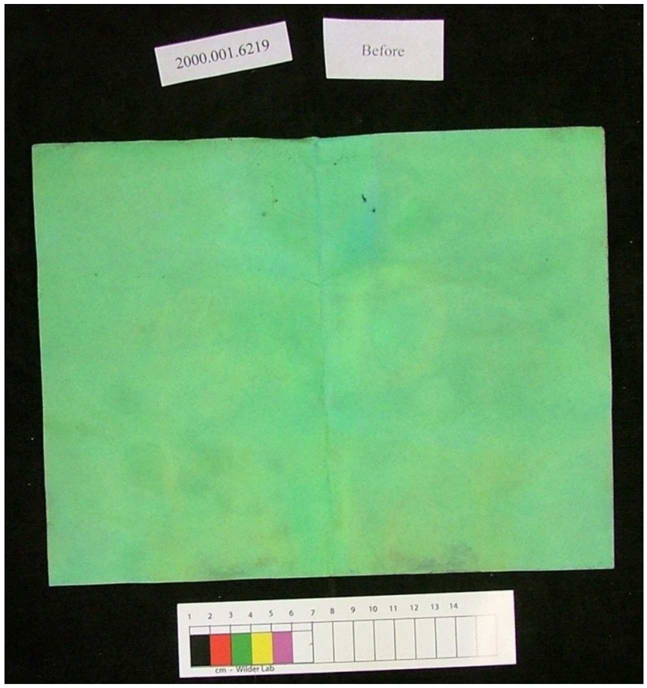
Testing:
ink
lights

Conclusions:
looks lots better and is much stronger

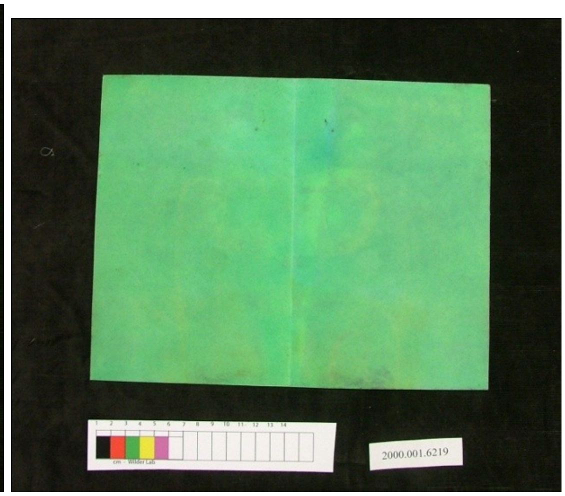
Graphic Record

	Before	During	After
Color photo	x		x

Additional Comments:


2000.001.6219
Before
cm - Wilder Lab


cm - Wilder Lab
2000.001.6219


2000.001.6219

Artifact 1988/a/fea4

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 10/13/05 **Artifact No.** 1988/a/fea4 **Initials** ebe

Description and Condition:
Wjite paper 8.5x11 on an album page with scotch tape and laminate. Lotse of scotch tape running down the side
surface dirt and mold
saftey pin
media in pencil
"To the parents..."
very brittle
candle wax os some other oil

Proposed Treatment:
remove album page and acetate
remove tape
Mechamically clean
humidify
mend tears
MTMS/Si treatment

Results: ☒ Excellent ☒ Good ☐ Fair ☐ Poor

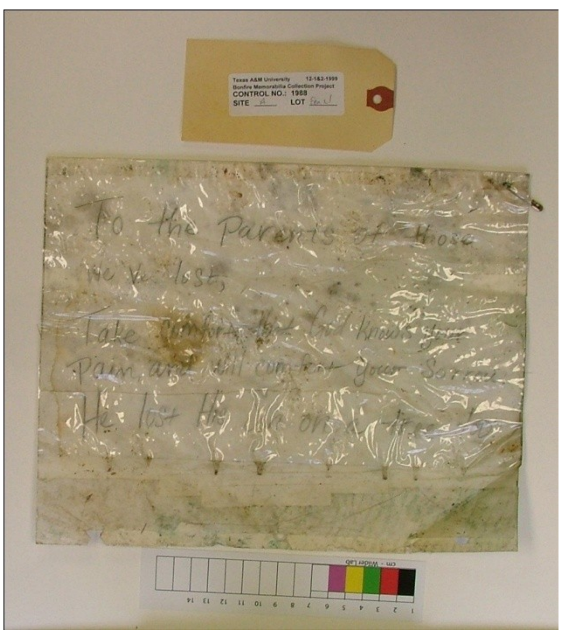
Testing:
lights-nothing

Conclusions:
This was an ordeal. The tape only came off with acetone, but left alot of adhesive. It was a very lengthy process to remove the adhesive, rendering the taped area very weak. Originally, it was thought that this would need to be back as it was so week and fragile, but I went out on a limb and decided to forgo the backing-since a minimal amount of intrusive material is the goal and a few little mends should do the job, rather I would put into treatment alone. After it came out it was strong and flexible and I did not worry about tears or handling. IT feels and looks as good as it could-better in fact.

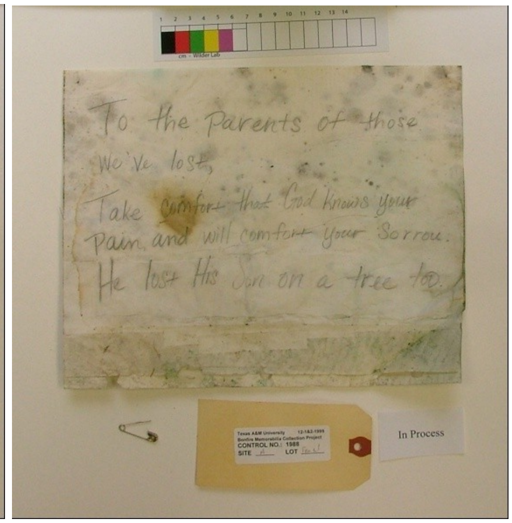
Graphic Record

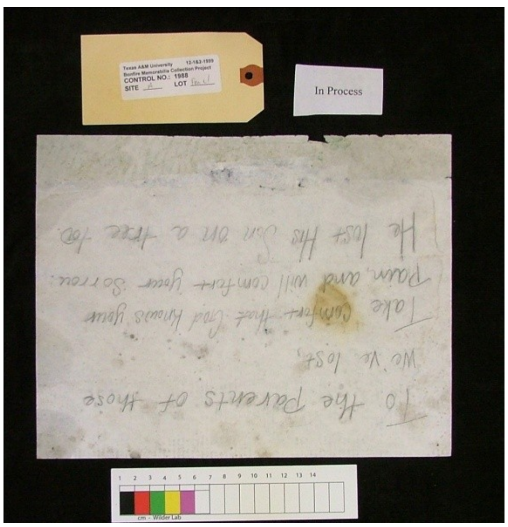
	Before	During	After
Color photo	x	x	x

Additional Comments:

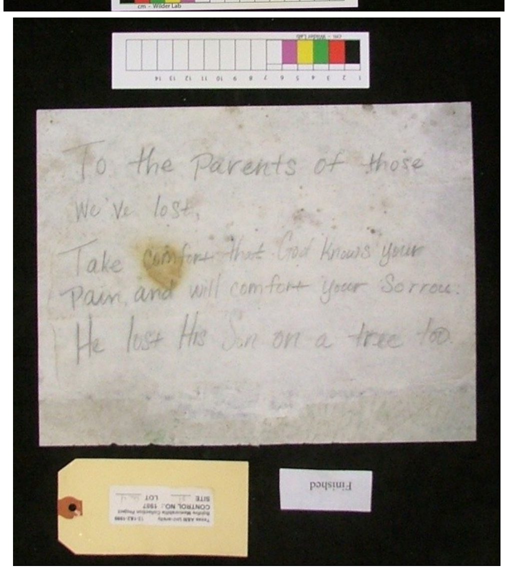



In Process


To the Parents of those
We've lost,
Take comfort that God knows your
Pain, and will comfort your Sorrow.
He lost His Son on a tree too.
In Process


In Process


In Process


To the Parents of those
We've lost,
Take comfort that God knows your
Pain, and will comfort your Sorrow.
He lost His Son on a tree too.

Artifact 2000.001.3832

Bonfire Memorabilia Project
Archaeological Preservation Research Laboratory
Texas A&M University

Date 11/11/05 **Artifact No.** 2000.001.3832 **Initials** ebe

Description and Condition:
wad of paper 1.5 ft x7inx9in
very water damaged
scooped up with a shovel after lying on the concrete
leaves
candle wax
lots of surface dirt
mold
hair
burnt areas
severely wrinkled and creased

Proposed Treatment:
manually unroll
mechanically clean
flatten using spray bottle
flatten
back
flatten
Spray MTMS/si

Results: ☒ Excellent ☐ Good ☐ Fair ☐ Poor

Testing:
Lights
ink

Conclusions:
After about 50-60 hours of labor, it is amazing how much was recovered and able to be conserved and restored. It had to be carefully hand-flattened and maintained. The were about fifty individual pieces with good markers as to their placement. One piece made up about sixty percent and was retained intact. fitting the pieces back together was very problematic, since the paper was stretched and shrunken and oddly creased, but attempts were made to keep diagnostic areas (areas where there was intact writing) more complete. Backing posed issues as well, as it was very difficult to maintain the right glue consistency. As a result it would probably be wise to re-paste area on the poster over time, especially if it is stored upright or rolled, instead of flattened.

Graphic Record

	Before	During	After
Color photo	x	x	x

Additional Comments:

The original condition of the poster: it had been rained on and was scraped up using a shovel.




The poster was unraveled as much as possible using care and humidity chambers.

It was pressed between blotters to flatten with weight placed on trays.

It soon became apparent that a large area for assemblage was necessary, so several tables were positioned together with sheets of spun polyester for support.







COYKent


LOVELADY


COYKent

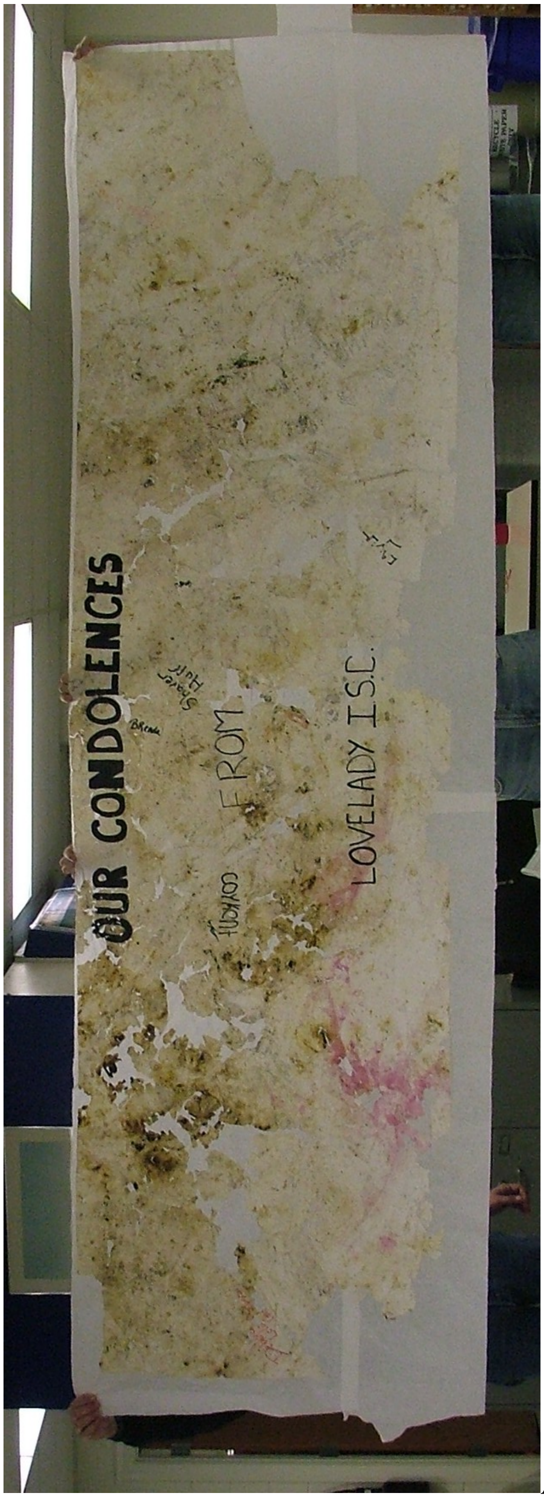






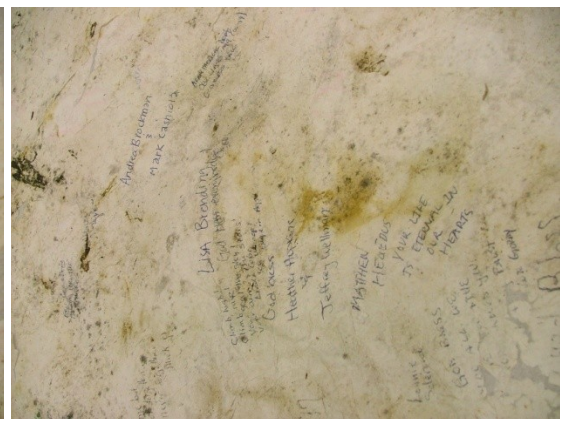


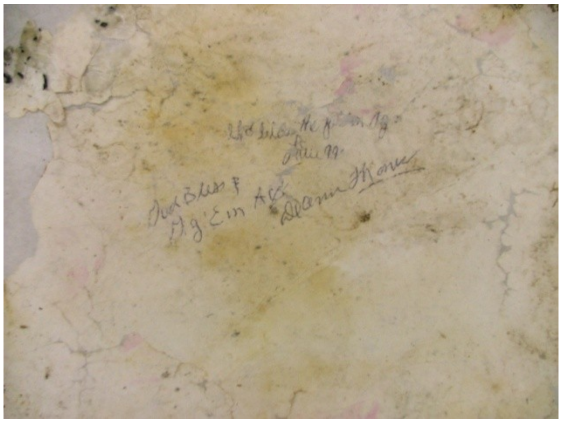
After the poster was completely flattened and put into its place, it was determined that it should be mounted on rice paper using wheat starch paste.

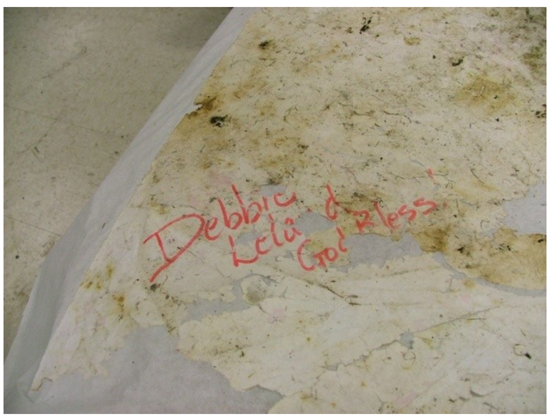


After it was secured to the rice paper, MTMS solution was sprayed onto the poster making it stronger and more flexible, so it could be easily transported, displayed, and stored. The poster was 38 inches by 130 inches.

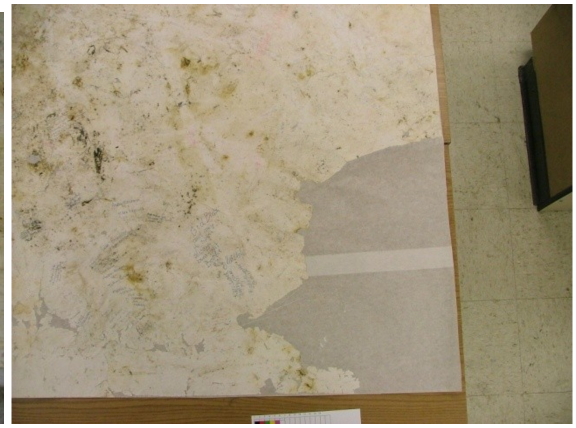
The rest of the images are upclose images of some of the details of the poster.






Debbie & Lela God Bless


NCES




OLENCES


CONDOLENCES
FROM
VELADY I.S.C.


OUR CONDOL
FROM
LOVELADY

VITA

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